# TITAN II

## STORABLE PROPELLANT HANDBOOK

### JUNE 1961

# TITAN II STORABLE PROPELLANT HANDBOOK

## Final Handbook

**BELL AEROSYSTEMS COMPANY**
Division of Bell Aerospace Corporation
Buffalo 5, New York

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Report No. 8111-933003

Contract No. AF04(611)-6079
Project 6753
Task 30282

JUNE 1961

**AIR FORCE FLIGHT TEST CENTER**
Edwards Air Force Base
California

# FOREWORD

This is the third and final report prepared for the Air Force Flight Test Center by the Bell Aerosystems Company under Contract AF04(611)-6079, "Storable Propellant Data for the Titan II Program," Project 6753 and Task 30282. Mr. C.F. Emde (FTRLP) of AFFTC was Program Manager and Mr. Glen W. Howell of the Space Technology Laboratories, Los Angeles, California, was Coordinator. Mr. Ralph R. Liberto, Project Engineer of Bell Aerosystems, directed the study effort. Research under this contract started on 15 June 1960 and ended on 15 April 1961. Results of the effort are reported in this handbook. At a later date, a revision to this handbook will be prepared as part of the task under Contract AF04(647)-846.

Harold W. Stafford
Technical Editor

## ABSTRACT

Summarized are the physical properties, materials compatibility, handling techniques, flammability and explosivity, and procedures for storing, cleaning, and flushing of the Titan II propellants, $N_2O_4$ as the oxidizer and a nominal 50/50 blend of UDMH and $N_2H_4$ as the fuel. The data presented was derived both from a literature survey and from a test program conducted at Bell Aerosystems Company and at the U.S. Bureau of Mines.

## TABLE OF CONTENTS

## ILLUSTRATIONS

# LIST OF TABLES

## SYMBOLS/ABBREVIATIONS USED IN THE TEXT

| | |
|---|---|
| AFBMD | Air Force Ballistic Missile Division |
| AFFTC | Air Force Flight Test Center |
| ARDC | Air Research and Development Command |
| ADL | Arthur D. Little, Inc. |
| JPL | Jet Propulsion Laboratory |
| STL | Space Technology Laboratories, Inc. |
| AEROZINE-50 | Trade name adopted by Aerojet-General (Nominal 50/50 blend by weight of UDMH and $N_2H_4$) |
| 50/50 FUEL BLEND | Nominal 50/50 blend by weight of UDMH and $N_2H_4$ |
| $NO_2$ | Nitrogen Dioxide |
| $N_2H_4$ | Hydrazine, Specification Grade MIL-P-26536A (USAF) |
| $N_2O_4$ | Nitrogen Tetroxide, Specification Grade MIL-P-26539 (USAF), an Equilibrium Mixture of $NO_2$ and $N_2O_4$ |
| RFNA | Red Fuming Nitric Acid |
| UDMH | Unsymmetrical Dimethylhydrazine, Specification Grade MIL-D-25604B(ASG) |
| M.A.C. | Maximum Allowable Concentration |
| MPY | Mils per Year |
| ppm | Parts per Million by Volume |
| RASCAL | Components of the LR-67-BA-9 rocket engine produced by Bell Aerosystems for the GAM-63A (RASCAL) Missile |
| SIT | Spontaneous Ignition Temperature(s) |

Metal and alloy designations used in this handbook, such as type 304SS, are those established by the cognizant agencies and used in the trade.

# SECTION 1.0

# INTRODUCTION

SECTION 1.0

INTRODUCTION

A storable propellant combination of $N_2O_4$ as the oxidizer, and a nominal 50/50 blend of UDMH and $N_2H_4$ as the fuel, has been selected for the Titan II ballistic missile. These propellants were studied by Bell Aerosystems Company and the resultant data on physical properties, materials compatibility, handling, safety, and flammability and explosivity is published in this handbook. The information was compiled from industry and government data and from trade literature. Laboratory tests were conducted to augment available data and to help in analyzing information.

# SECTION 2.0

## PHYSICAL PROPERTIES OF 50/50 FUEL BLEND

SECTION 2.0

PHYSICAL PROPERTIES OF 50/50 FUEL BLEND

The fuel blend, comprising a 50/50 mixture of UDMH and $N_2H_4$, is a clear, colorless, hygroscopic (capable of absorbing moisture readily) liquid having a characteristic ammoniacal odor. When the blend is exposed to air, a distinct fishy odor is evident in addition to the ammonia odor; this is probably caused by the air oxidation of UDMH.

The UDMH and $N_2H_4$ are miscible in all proportions. When combined, there is an immediate tendency for each to dissolve in the other. However, because of their different densities, they are easily layered; UDMH above the $N_2H_4$, especially when UDMH is poured into a vessel containing $N_2H_4$. Under these conditions, a distinct interface may form (Reference 1).

In the pages that follow, additional physical property data is presented for this fuel blend. The information was obtained from the literature or from laboratory tests conducted at Bell Aerosystems. Table 2.1 summarizes pertinent physical properties of the fuel blend.

The boiling point of the fuel blend listed in Table 2.1 is interpolated from the measured vapor pressure data plotted in Figure 2.4. At the boiling point, the concentration of UDMH in the vapor phase is approximately 92% by weight. At 77°F, the concentration of UDMH in the vapor phase is approximately 95% by weight (Reference 1). During distillation of this blend, a wide temperature range is noted between the point at which 10% by volume is distilled and the 90% by volume is distilled. This temperature difference is 80°F (Table 2.6). This blend is not a constant boiling mixture.

TABLE 2.1

PHYSICAL PROPERTIES OF THE 50/50 FUEL BLEND

| | $N_2H_4$ | UDMH |
|---|---|---|
| Structural Formula of the Fuel | (structure) | (structure) |
| Molecular Weight (ave) | 45.0 | |
| Melting Point [a] | 18.8°F | |
| Boiling Point [a] | 158.2°F | |
| Physical State | Colorless Liquid | |
| Density of Liquid at 77°F [a] | 56.1 lb/ft$^3$ | |
| Viscosity of Liquid at 77°F [a] | 54.9 x 10$^{-5}$ lb/ft-sec | |
| Vapor Pressure at 77°F [b] | 2.75 psia | |
| Critical Temperature (calc) | 634°F | |
| Critical Pressure (calc) | 1696 psia | |
| Heat of Vaporization (calc) | 425.8 BTU/lb | |
| Heat of Formation at 77°F (calc) | 527.6 BTU/lb | |
| Specific Heat at 77°F (calc) | 0.694 BTU/lb-°F | |
| Thermal Conductivity at 77°F (calc) | 0.151 BTU/ft-hr-°F | |
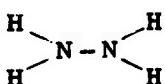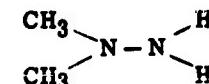
a - Measured on samples of the fuel blend of typical composition (51.0% $N_2H_4$, 48.2% UDMH, and 0.5% $H_2O$).

b - Fuel blend composition 51.0% $N_2H_4$, 48.4% UDMH, and 0.6% $H_2O$.

(Reference 1)

2 1    FUEL BLEND SPECIFICATION

A tentative specification, MIL-P-27402(USAF), is available for the 50/50 fuel blend. This specification contains a method for performing analyses to fulfill the chemical requirements given in Table 2.2. This method is the salicylaldehyde method which is based upon a differential titration and determines UDMH directly and $N_2H_4$ indirectly. Water content and other soluble impurities are calculated by difference.

### TABLE 2.2

### PROPELLANT SPECIFICATION — 50/50 FUEL BLEND

| Chemical Requirements | Specification (wt %, |
|---|---|
| UDMH | 47.0 (min) |
| $N_2H_4$ | 51.0 ±0.8 |
| Total $N_2H_4$ and UDMH | 98.2 (min) |
| $H_2O$ and Other Soluble Impurities | 1.8 (max) |

2.2   MELTING POINT

Figure 2.1 contains melting point data for various mixtures of UDMH and $N_2H_4$ obtained from JPL, Aerojet-General Corporation, and Bell Aerosystems Company.  The Bell and Aerojet data for the fuel blend composition agree.  The melting point of the fuel blend, as estimated by Aerojet, can range from about 17° to 21°F, thereby meeting the composition requirements of the procurement specification (see Table 2.2).

MELTING POINT —
°F

JPL
AEROJET-GENERAL
BELL AEROSYSTEMS
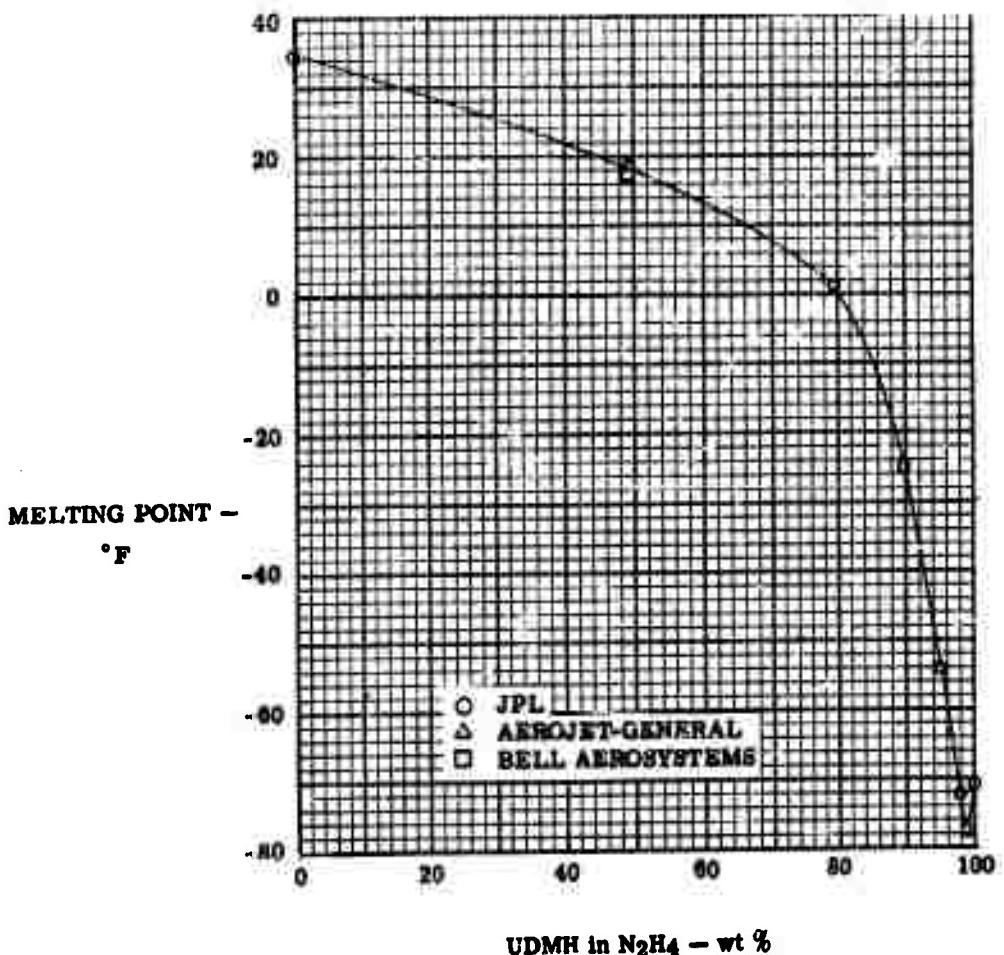
UDMH in $N_2H_4$ — wt %

Figure 2.1. Melting Point vs Percent Weight of UDMH in $N_2H_4$

2.3    DENSITY

Figures 2.2 and 2.3 present density and specific gravity data for the fuel blend as reported by Aerojet-General Corporation (Reference 1).

DENSITY — lb/cu ft



TEMPERATURE — °F
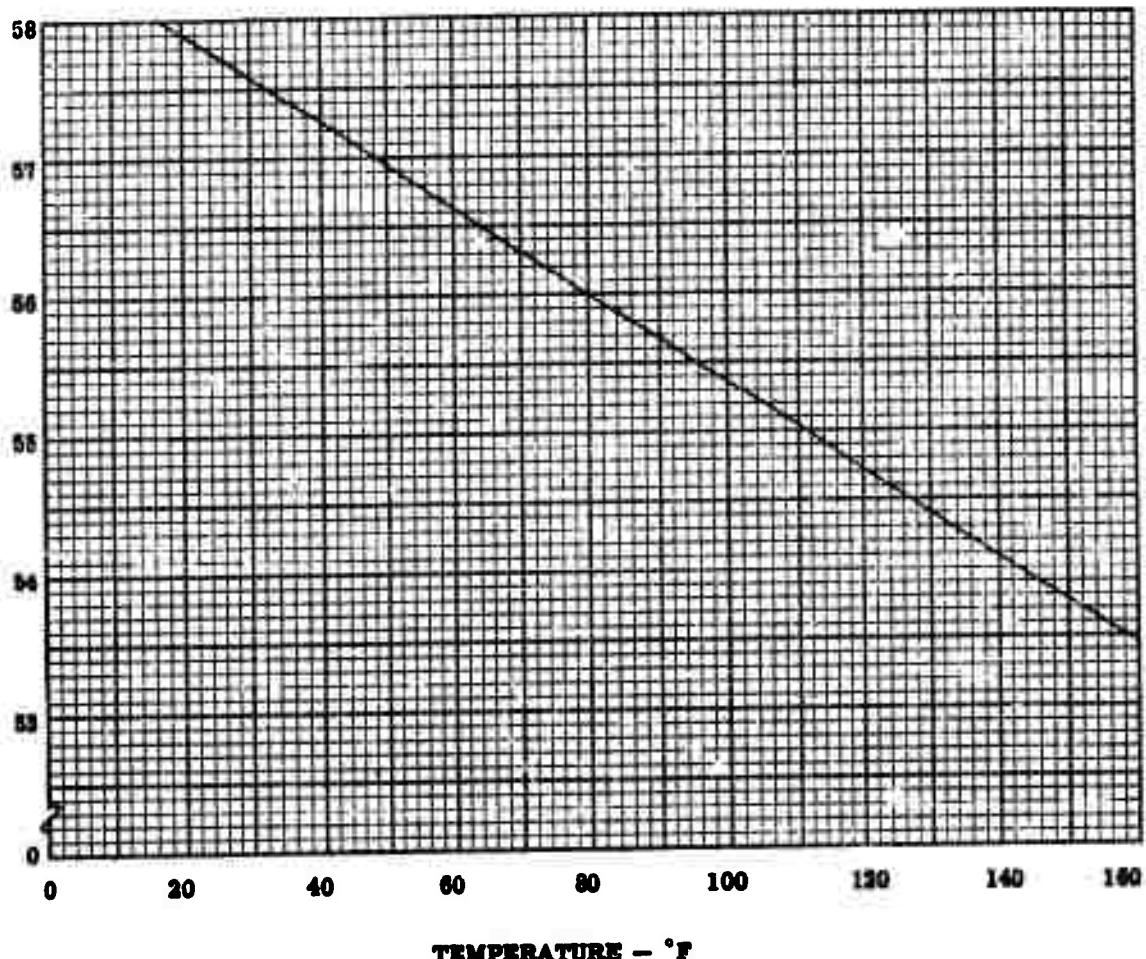
(Reference 1)

Figure 2.2. Density of 50/50 Fuel Blend

SPECIFIC GRAVITY



TEMPERATURE — °F
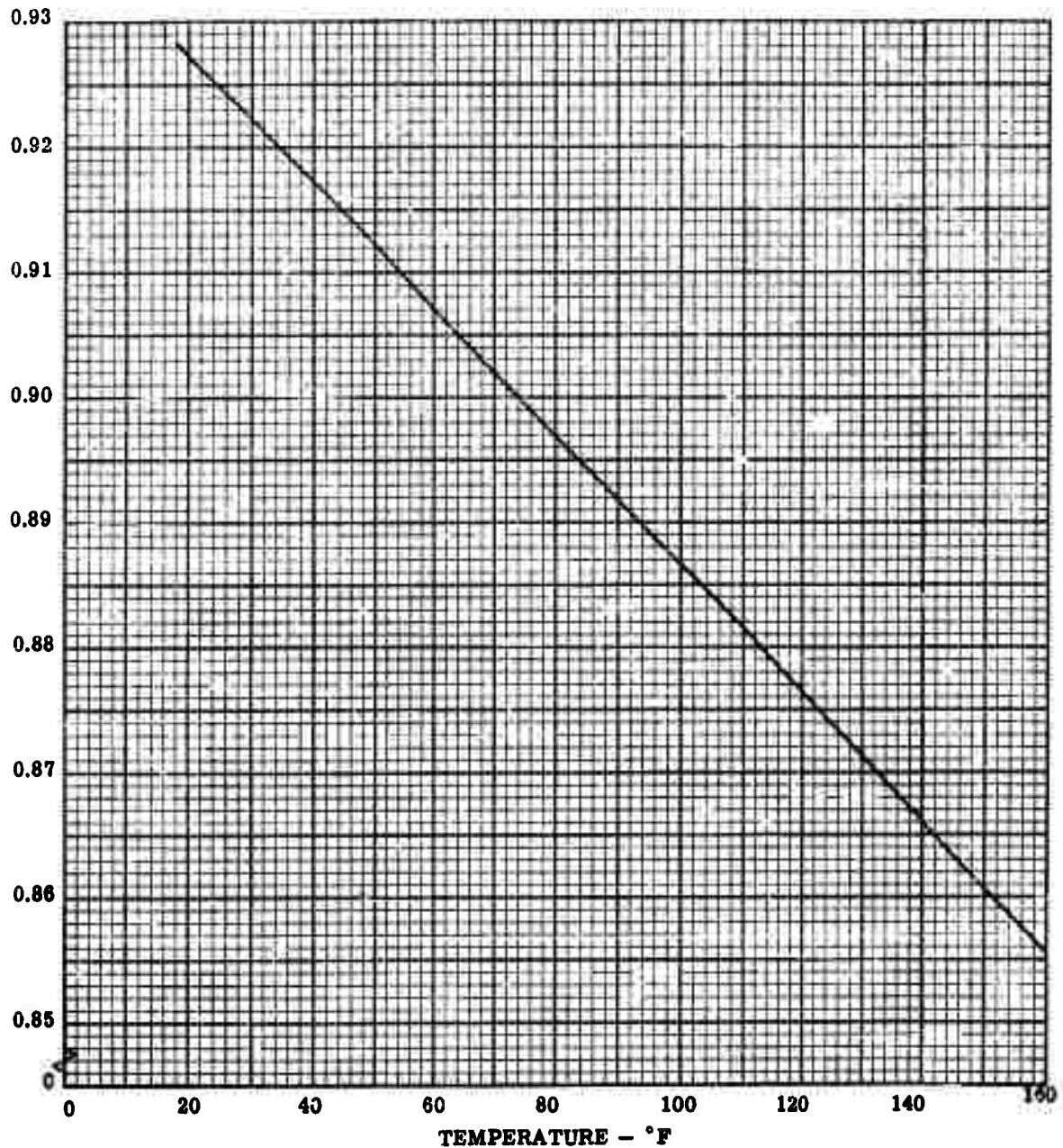
(Reference 1)

Figure 2.3. Specific Gravity of 50/50 Fuel Blend

## 2.4 VAPOR PRESSURE

This fuel is a mixture of UDMH and $N_2H_4$, with UDMH possessing the higher vapor pressure. The vapor pressure of a liquid mixture depends upon the composition of the mixture and is the sum of the partial pressures of each gas at a constant temperature. However, as one of the more-volatile components vaporizes from a liquid mixture (in this case UDMH) into a large volume space (ullage) above it, the vapor pressure of the resulting liquid mixture decreases. Inversely, as the volume space above the liquid mixture decreases, the vapor pressure of the liquid increases. A preliminary experiment was conducted at Bell to determine the effect this would have when the vapor pressure of the fuel blend was measured at different ullages employing an all-glass evacuated system and an isoteniscope. At 80°F, the vapor pressure at 20% ullage was 3.7 psia, at 50% ullage 3.3 psia, and at 75% ullage 2.3 psia. Although the fuel blend used was slightly out of specification, the effect of ullage was demonstrated.

Table 2.3 and Figure 2.4 contain the vapor pressure of the 50/50 fuel blend at various temperatures and at 46% ullage. The Bell experimental points were obtained with the apparatus shown and described in Reference 2.

### TABLE 2.3

### VAPOR PRESSURE OF 50/50 FUEL BLEND AT 46% ULLAGE

| Temperature (°F) | Vapor Pressure (psia) |
|---|---|
| 14.0 [a] | 0.55 |
| 23.0 [a] | 0.71 |
| 32.0 [a] | 0.92 |
| 68.0 [a] | 2.09 |
| 77.0 [a] | 2.75 |
| 85.3 [b] | 3.08 |
| 86.0 [a] | 3.42 |
| 104.0 [a] | 5.00 |
| 108.9 [b] | 5.30 |
| 122.0 [a] | 7.30 |
| 135.3 [b] | 9.29 |
| 140.0 [a] | 10.50 |
| 159.8 [a] | 15.10 |

a - Aerojet-General Corporation experimental data  (Reference 1).

b - Bell Aerosystems Company experimental data (Reference 2).

PRESSURE — psia
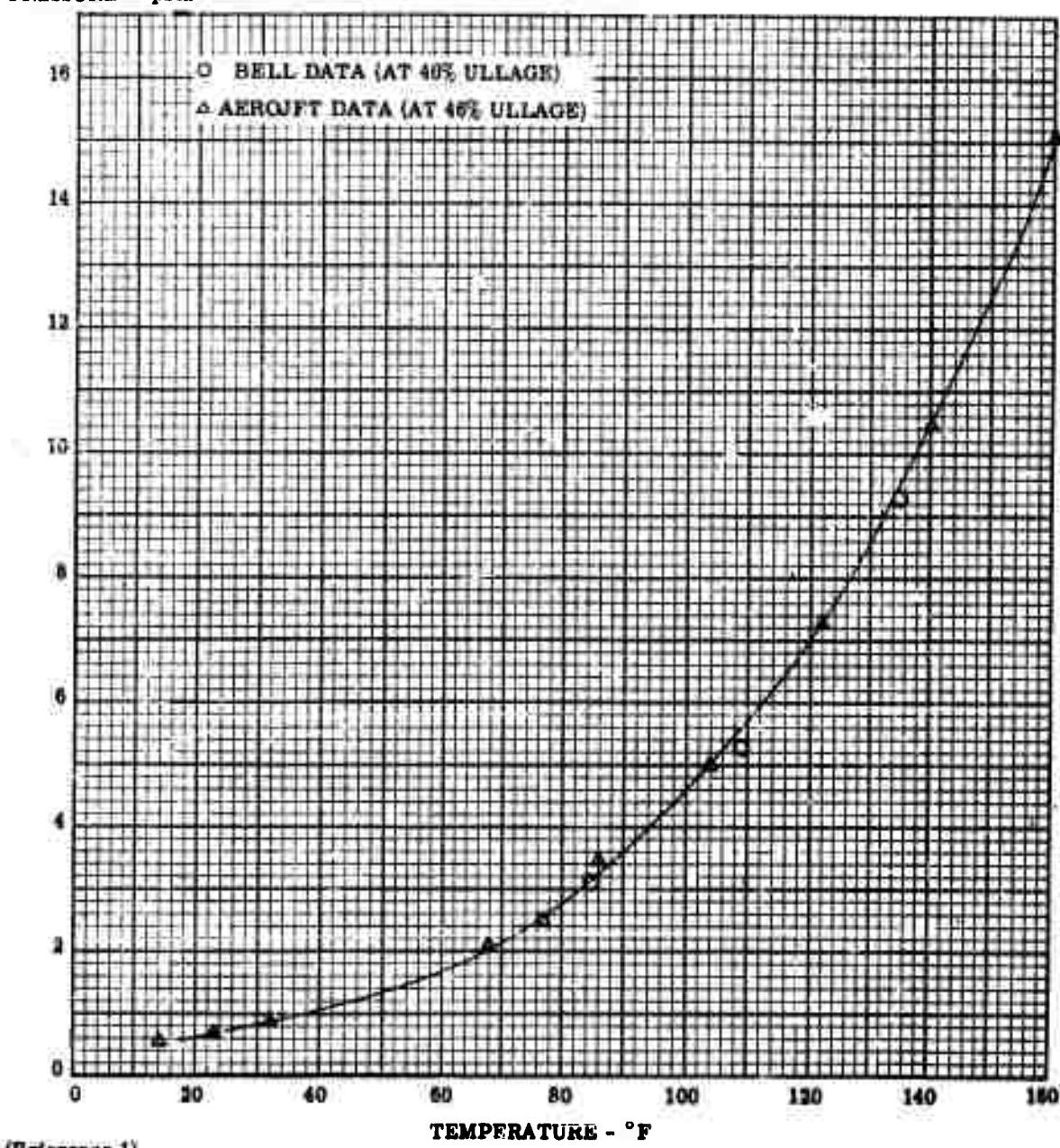


Figure 2.4. Vapor Pressure of 50/50 Fuel Blend

TEMPERATURE - °F

(Reference 1)

2.5 VISCOSITY

The viscosity of the 50/50 fuel blend was measured by Aerojet-General Corporation over the liquid range (Reference 1). Figure 2.5 is a plot of viscosity in centistokes versus temperature of the fuel blend.

VISCOSITY — centistoke
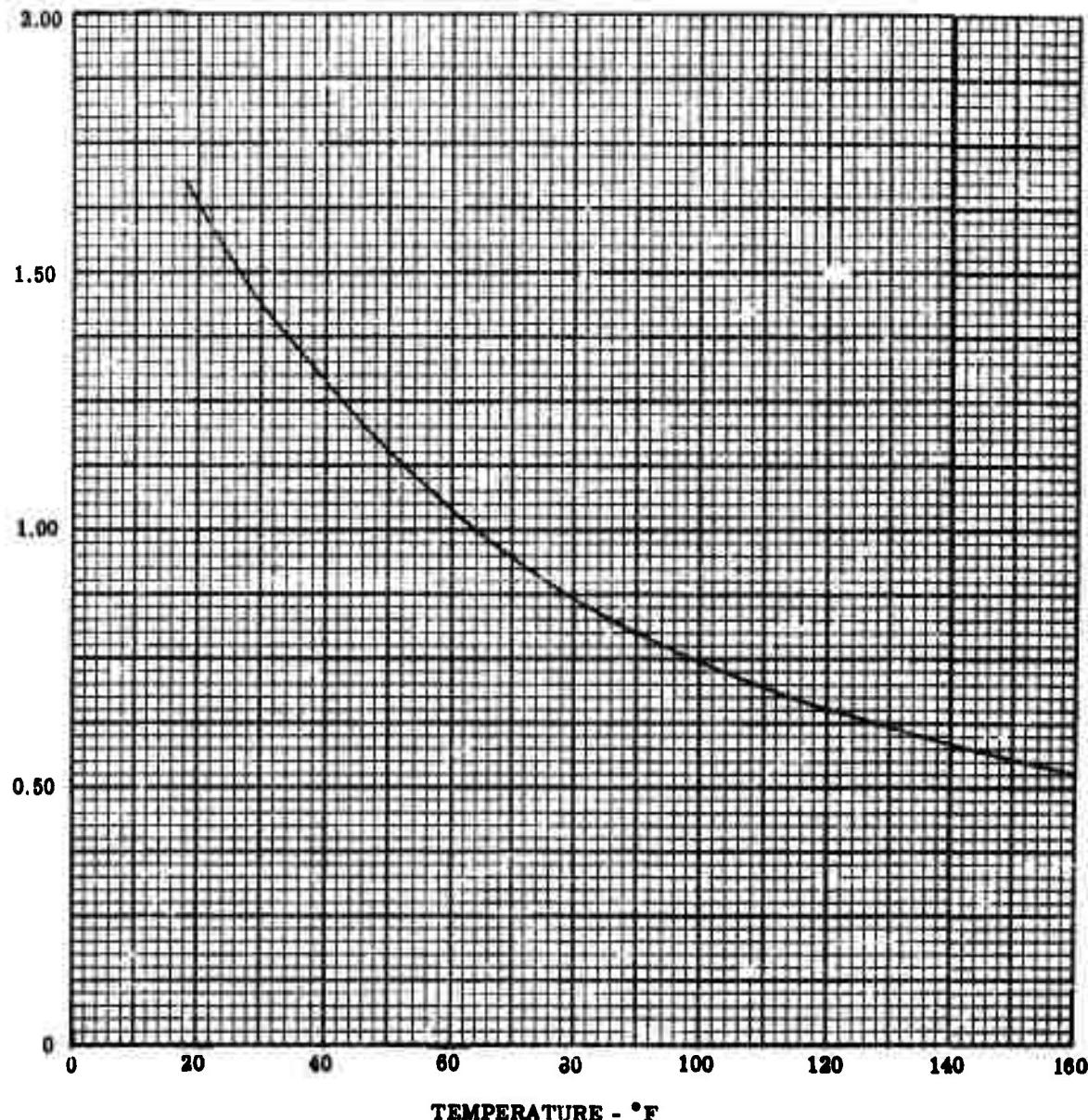


(Reference 1)

Figure 2.5. Viscosity of 50/50 Fuel Blend

2.6   HEAT CAPACITY

Heat capacity data of the 50/50 fuel blend, as calculated by Aerojet-General Corporation, is presented in Table 2.4 and plotted in Figure 2.6. Bell measured the heat capacity of the fuel blend at two temperatures using the method of mixtures described in Reference 2. The Bell experimental data agrees within 0.5% of the Aerojet calculated data.

TABLE 2.4

HEAT CAPACITY OF 50/50 FUEL BLEND

(Calculated by Aerojet-General)

| Temperature (°F) | Heat Capacity (BTU/lb-°F) |
|---|---|
| 21 | 0.680 |
| 35 | 0.684 |
| 63 | 0.692 |
| 81 | 0.696 |
| 99 | 0.702 |
| 135 | 0.709 |
| 153 | 0.715 |
| 250 | 0.743 |
| 350 | 0.780 |
| 420 | 0.814 |
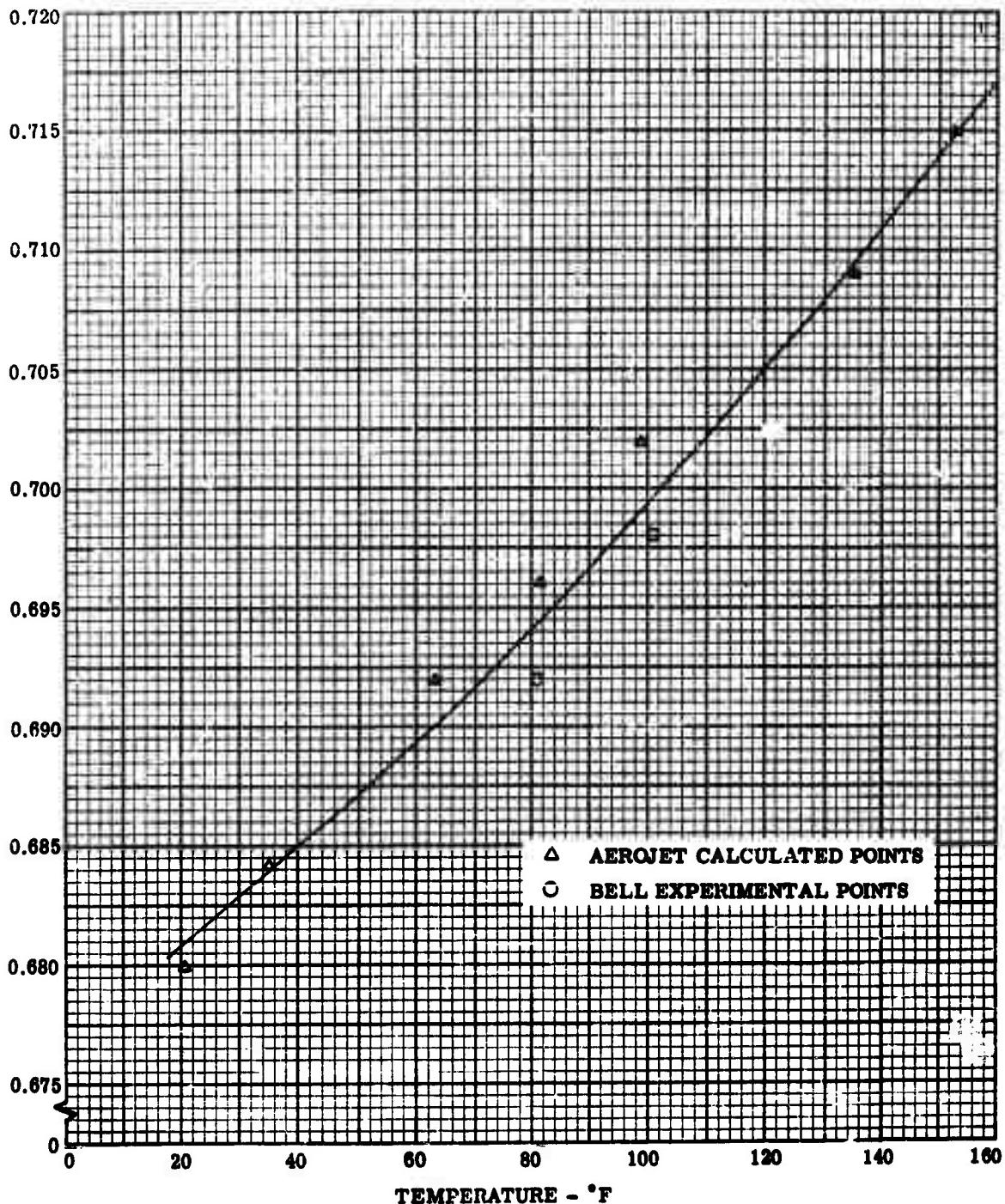
Figure 2.6. Heat Capacity of 50/50 Fuel Blend

2.7   FLASH AND FIRE POINTS

Flash and fire point measurements made with a modified Cleveland Open-Cup Tester (Reference 2) resulted in the data presented in Table 2.5 and plotted in **Figure 2.7.** The tests indicate that the fuel blend must be diluted with at least an equal volume of water before the fire hazard is reduced appreciably. A dilution of three volumes of water to two volumes of fuel blend is required to increase the flash and fire point temperature to 160°F.

TABLE 2.5

FLASH AND FIRE POINTS OF 50/50 FUEL BLEND
WITH VARIOUS WATER DILUTIONS

(Using a Modified Cleveland Open-Cup Tester)

| $H_2O$ in Fuel Blend (vol %) | Flash Point (°F) | Fire Point (°F) |
|---|---|---|
| Undiluted | 38 | 38 |
| 10 | 40 | 40 |
| 20 | 35 | 35 |
| 50 | 110 | 125 |
| 60 | 160 | 160 |
| 65 | 180 | 200 |
| 75 | > 212 | > 212 |
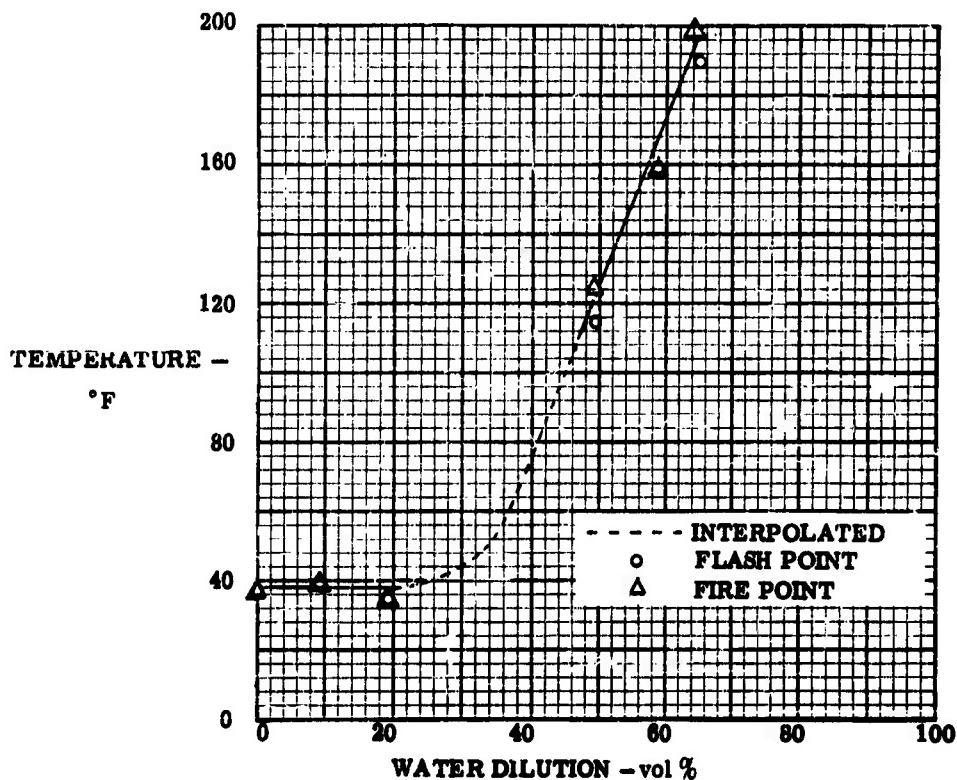
(Reference 2)

Figure 2.7. Flash and Fire Points of 50/50 Fuel Blend with Various Water Dilutions

## 2.8  DISTILLATION RANGE

The distillation range of the 50/50 fuel blend, together with analyses of various fractions, is shown in Table 2.6. When the fuel blend is heated, the initial condensed vapors are richer in the more-volatile UDMH; as the distillation process continues with increasing temperature, the condensed distillate becomes richer in the less-volatile $N_2H_4$.

### TABLE 2.6

### DISTILLATION RANGE OF THE 50/50 FUEL BLEND

| Blend Composition by Weight % | |
|---|---|
| UDMH | 48.7 |
| $N_2H_4$ | 50.4 |
| $H_2O$ + impurities | 0.9 |

| Temperature (°F) | Volume % (Distilled) | Distillate Analyses |
|---|---|---|
| 149.0 | First Drop Distilled | - |
| 158.0 | 10 | 86.0% UDMH, 8.0% $N_2H_4$ |
| 161.6 | 20 | 85.0% UDMH, 9.0% $N_2H4$ |
| 167.0 | 30 | - |
| 170.6 | 40 | - |
| 194.0 | 50 | 79.0% UDMH, 16.0% $N_2H_4$ |
| 233.6 | 60 | - |
| 235.4 | 70 | - |
| 235.4 | 80 | 100% $N_2H_4$ |
| 239.0 | 90 | 95% $N_2H_4$ |

NOTE: Fuel fractions were analyzed spectrally employing calibration curves covering the UDMH and $N_2H_4$ concentration range of 45% to 55% by weight. The analytical results, obtained by extrapolating the calibration curves, are approximate. $N_2H_4$ at the 90% fraction probably contains hydrazine hydrate.

(Reference 2)

2.9    SOLUBILITY OF PRESSURIZING GASES

The solubility of nitrogen, helium, and ammonia in the 50/50 fuel blend was determined using the apparatus shown in Reference 2 and the procedure described in Reference 3. Results of these tests are shown in Table 2.7.

TABLE 2.7

SOLUBILITY OF VARIOUS GASES IN 50/50 FUEL BLEND

| Pressurizing Gas | Temperature (°F) | Solubility (wt %) | Final Gas Pressure (psia) |
|---|---|---|---|
| Nitrogen | 70.0 | < 0.01 | 86.0 |
|  | 32.0 | < 0.01 | 79.4 |
| Helium | 71.5 | 0.012 ± 0.008 | 63.6 |
|  | 33.0 | < 0.008 | 60.7 |
| Ammonia | 57.5 | 0.26 ±0.01 | 38.0 |
|  | 70.0 | 0.25 ±0.01 | 44.4 |

2.10  SHOCK SENSITIVITY

To determine the shock sensitivity of the 50/50 fuel blend, tests were conducted at room temperature using a drop-weight tester and a procedure developed by Olin Mathieson Chemical Corporation. The procedure is acceptable to the Joint Army-Navy-Air Force Panel on Liquid Propellant Test Methods. Results of these tests show that the liquid fuel blend is not shock sensitive at the highest impact value (8 foot-pounds) produced by the tester (Reference 2).

# SECTION 3.0

# PHYSICAL PROPERTIES OF N₂O₄

# SECTION 3.0

## PHYSICAL PROPERTIES OF $N_2O_4$

The compound $N_2O_4$ is an equilibrium mixture of nitrogen tetroxide and nitrogen dioxide ($N_2O_4 \rightleftharpoons 2NO_2$). At 68°F and at a pressure of one atmosphere, the liquid consists of 84.2% $N_2O_4$ in equilibrium with 15.8% $NO_2$ as shown in Table 3.1 and Figure 3.1.

In the solid state, $N_2O_4$ is colorless; in the liquid state, the equilibrium mixture is yellow to red-brown; and in the gaseous state, it is red-brown. The fumes exhibit a characteristic pungent and irritating odor.

The oxidizer, $N_2O_4$, reacts with water forming nitric acid and nitrous acid. The nitrous acid undergoes decomposition immediately forming additional nitric acid and evolving nitric oxide (Reference 30). This strong oxidizer is hypergolic with fuels such as UDMH, $N_2H_4$, and aniline.

This section of the handbook contains physical property data for $N_2O_4$. The information was obtained from a literature survey. Table 3.2 summarizes the pertinent physical properties of $N_2O_4$.

## TABLE 3.1

### EQUILIBRIUM VALUES – PERCENT DISSOCIATION OF $N_2O_4$
### $N_2O_4 \rightleftharpoons 2NO_2$

| Temperature (°F) | Pressure (psia) | | |
|---|---|---|---|
| | 7.4 | 14.7 | 29.4 |
| 68 | 19.5 | 15.8 | 7.2 |
| 104 | 38.7 | 31.0 | 15.1 |
| 140 | 66.0 | 50.4 | 28.2 |
| 176 | 85.0 | 73.8 | 46.7 |
| 212 | 93.7 | 88.0 | 66.5 |

(Reference 5)
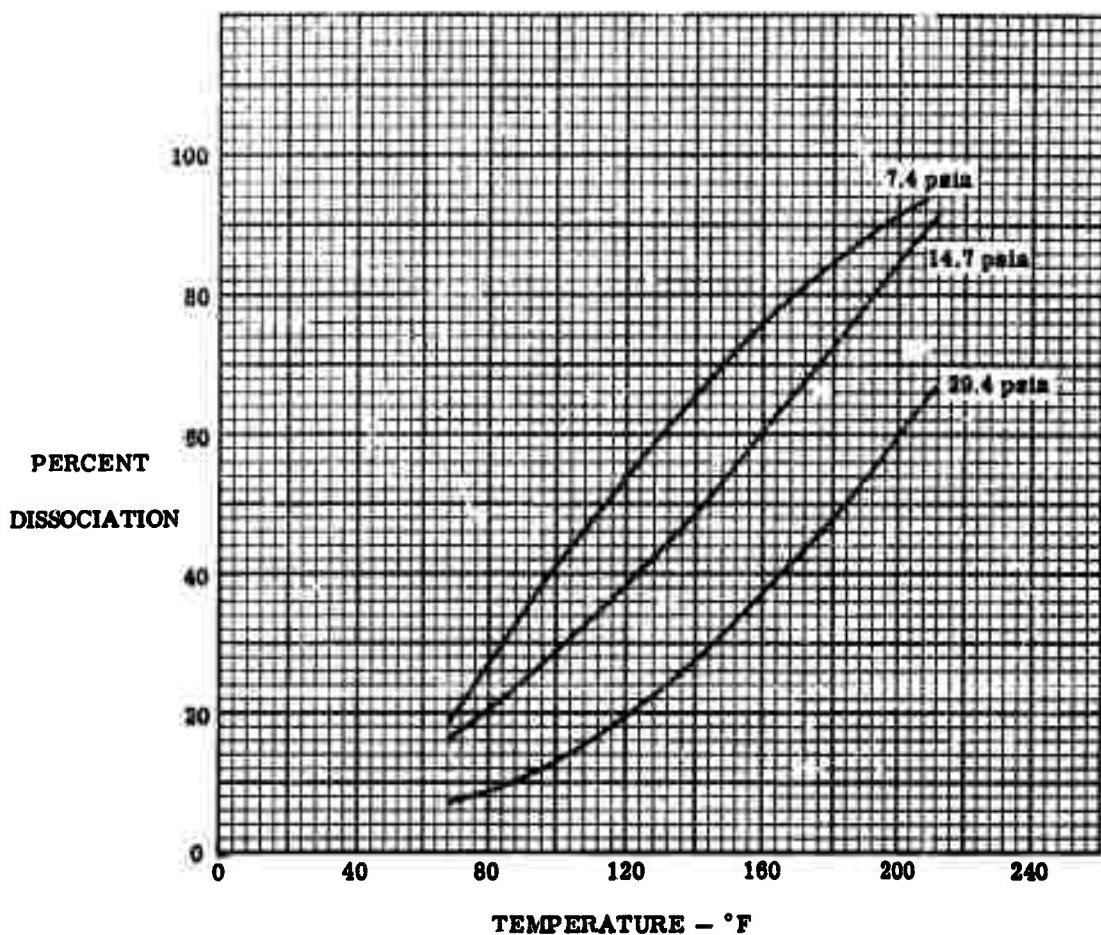
Figure 3.1. Equilibrium Values — Dissociation of $N_2O_4$

## TABLE 3.2

## PHYSICAL PROPERTIES OF $N_2O_4$

|  |  | Reference |
|---|---|---|
| Empirical Formula | $N_2O_4 \rightleftarrows 2NO_2$ | 5 |
| Structural Formula | | 6 |
| Molecular Weight | 92.016 | 5 |
| Physical State | Red-brown liquid | 5 |
| Melting Point | 11.84°F | 5 |
| Boiling Point | 70.07°F | 5 |
| Heat Formation at 77°F (Liquid) | -87.62 BTU/lb | 41 |
| Vapor Pressure at 77°F | 17.7 psia | 5 |
| Viscosity at 77°F | 0.0002796 lb/ft-sec | 7 |
|  | 0.410 centipoise | 7 |
| Density at 77°F | 89.34 lb/ft$^3$ | 5 |
| Heat Capacity at 70°F | 0.370 BTU/lb-°F | 5 |
| Critical Temperature | 316.8°F | 5 |
| Critical Pressure | 1469 psia | 5 |
| Thermal Conductivity at 40°F and 200 psia | 0.0812 BTU/ft-hr-°F | 5 |
| Heat Vaporization | 178 BTU/lb | 5 |
| Heat of Fusion | 68.4 BTU/lb | 5 |

## 3.1   $N_2O_4$ SPECIFICATION

The chemical requirements for procuring $N_2O_4$ were taken from Specification MIL-P-26539 (USAF) dated 18 July 1960. These requirements are presented in Table 3.3. The specification contains procedures for performing propellant analysis. The $N_2O_4$ assay is determined directly by titration. The water content is determined directly by evaporating $N_2O_4$ and weighing the nitric acid remaining. The water equivalent in this acidic non-volatile matter is based upon the assumption that it is 70% nitric acid. Nitrosyl chloride (NOCl) content is determined by colorimetric means. The non-volatile ash is determined by evaporating $N_2O_4$ to dryness and igniting the residue at high temperatures. The percentage of non-volatile ash is calculated from the ash that remains.

### TABLE 3.3

### PROPELLANT SPECIFICATION — $N_2O_4$

| Chemical Requirements | Specification (wt %) |
|---|---|
| $N_2O_4$ Assay | 99.5  (min) |
| $H_2O$  Equivalent | 0.1  (max) |
| Chloride as NOCl | 0.06 (max) |
| Non-Volatile Ash | 0.01 (max) |

## 3.2 VAPOR PRESSURE

Vapor pressure data, as a function of temperature, is presented in Table 3.4 and plotted in Figure 3.2.

TABLE 3.4

VAPOR PRESSURE OF $N_2O_4$

| Temperature (°F) | Vapor Pressure (psia) | Temperature (°F) | Vapor Pressure (psia) |
|---|---|---|---|
| 11.8 | 2.70 | 180 | 163.29 |
| 14 | 2.90 | 190 | 196.35 |
| 32 | 5.08 | 200 | 235.01 |
| 50 | 8.56 | 210 | 281.56 |
| 68 | 13.92 | 220 | 332.8 |
| 70 | 14.78 | 230 | 393.2 |
| 80 | 18.98 | 240 | 463.3 |
| 90 | 24.21 | 250 | 543.9 |
| 100 | 30.69 | 260 | 636.3 |
| 110 | 38.62 | 270 | 732.6 |
| 120 | 48.24 | 280 | 864.1 |
| 130 | 59.98 | 290 | 1000.5 |
| 140 | 74.12 | 300 | 1160.1 |
| 150 | 91.06 | 310 | 1336.5[a] |
| 160 | 111.24 | 316.8[b] | 1469.0[a] |
| 170 | 135.14 | | |

a - Value extrapolated.

b - Critical pressure estimated from measured critical temperature.

(References 1 and 5)

PRESSURE — psia
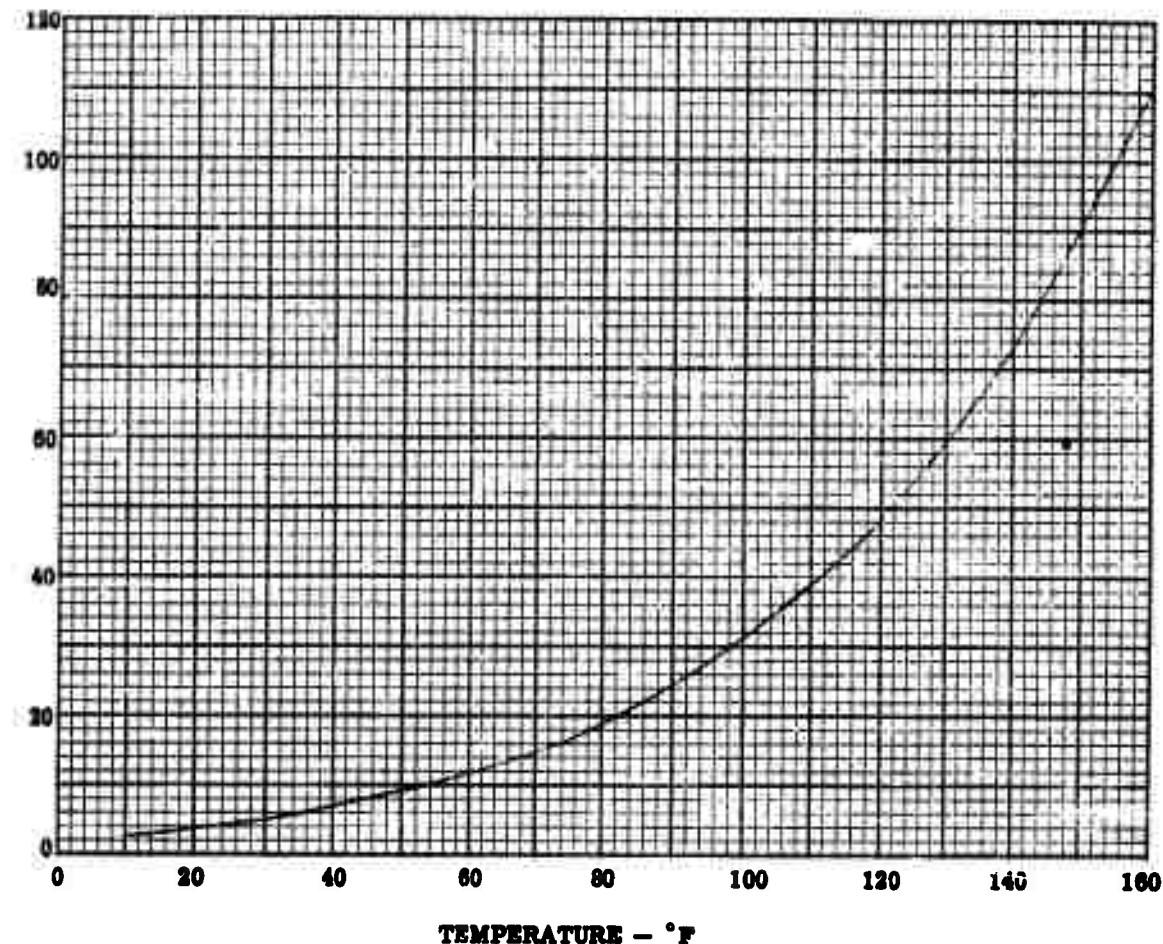


(References 1 and 5)

Figure 3.2. Vapor Pressure of $N_2O_4$

3.3   DENSITY

Table 3.5 and Figures 3.3 and 3.4 contain density and specific gravity values as a function of temperature for $N_2O_4$.

TABLE 3.5

DENSITY OF LIQUID $N_2O_4$

(Under its Own Vapor Pressure)

| Temperature (°F) | Specific Gravity | Density | |
|---|---|---|---|
| | | (lb/ft$^3$) | (lb/gal) |
| 11.8 | 1.515 | 94.54 | 12.62 |
| 32.0 | 1.490 | 93.05 | 12.44 |
| 50.0 | 1.470 | 91.77 | 12.27 |
| 68.0 | 1.447 | 90.34 | 12.09 |
| 77.0 | 1.431 | 89.34 | 11.94 |
| 95.0 | 1.412 | 88.15 | 11.76 |
| 104.0 | 1.400 | 87.40 | 11.66 |
| 113.0 | 1.388 | 86.61 | 11.56 |
| 118.4 | 1.379 | 86.05 | 11.49 |
| 122.0 | 1.375 | 85.80 | 11.45 |
| 129.2 | 1.363 | 85.05 | 11.35 |

(References 1 and 5)

DENSITY — lb/cu ft

TEMPERATURE — °F

Figure 3.3. Density of $N_2O_4$ Under its Own Vapor Pressure
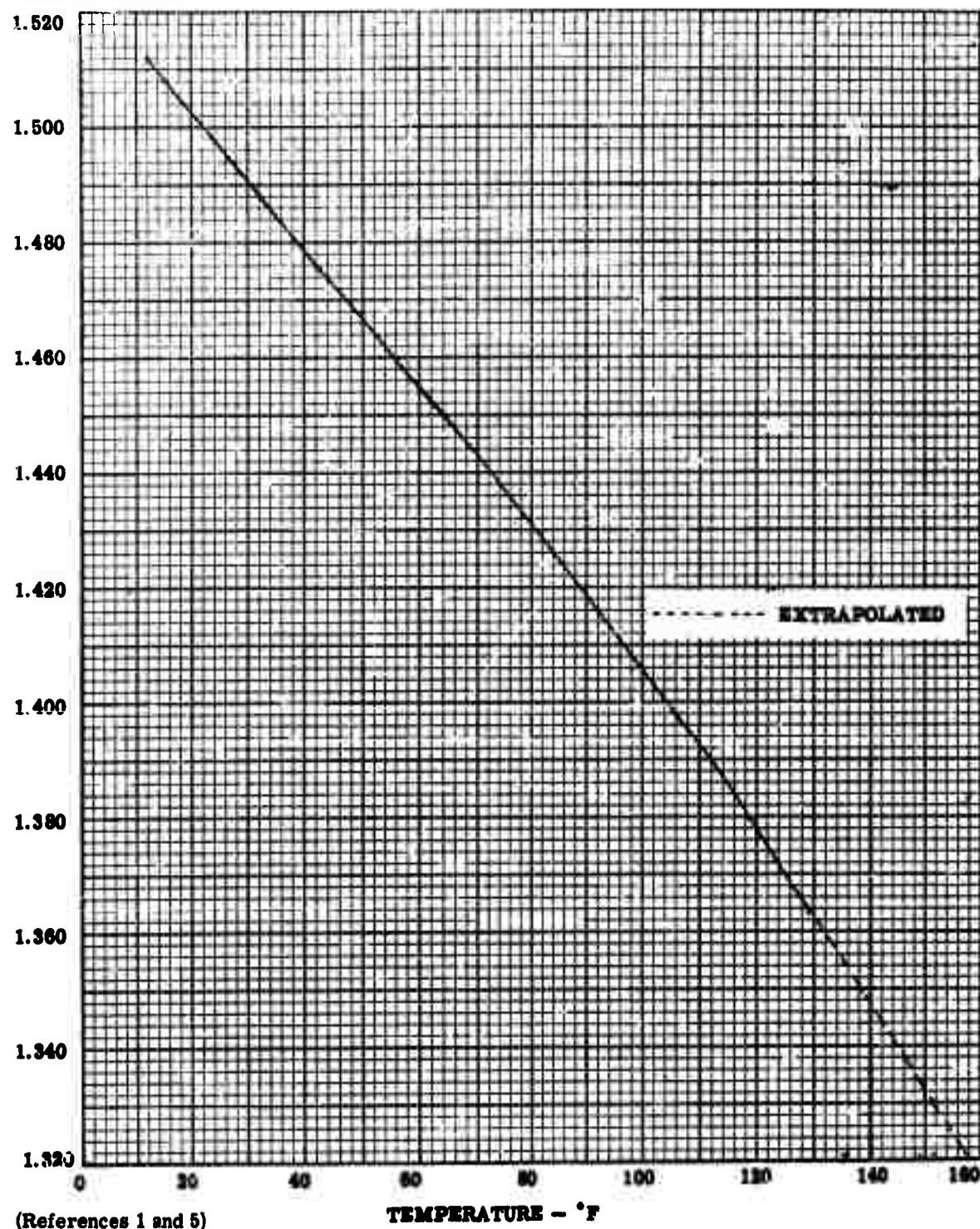
Figure 3.4. Specific Gravity of $N_2O_4$ Under its Own Vapor Pressure

(References 1 and 5)

## 3.4 VISCOSITY

The viscosity of $N_2O_4$ in the liquid phase from 40° to 280°F is presented in Table 3.6 and plotted in Figures 3.5 and 3.6. Figure 3.5 shows the effect of temperature on the viscosity of $N_2O_4$; Figure 3.6 shows the effect of pressure on viscosity of $N_2O_4$.

### TABLE 3.6

### VISCOSITY OF $N_2O_4$ IN THE LIQUID PHASE

| | Temperature (°F) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 40 | 70 | 100 | 130 | 160 | 190 | 220 | 250 | 280 |
| | | Bubble Pressure (psia) | | | | | | | |
| | | 14.8 | 30.7 | 60.0 | 111.2 | 196.4 | 332.8 | 543.9 | 864.1 |
| Pressure (psia) | | Viscosity (centipoise) | | | | | | | |
| Bubble Point | 0.4990 | 0.4132 | 0.3420 | 0.2784 | 0.2235 | 0.1752 | 0.1325 | 0.0924 | 0.0570 |
| 200 | 0.5021 | 0.4155 | 0.3441 | 0.2800 | 0.2250 | 0.1753 | | | |
| 400 | 0.5055 | 0.4180 | 0.3470 | 0.2820 | 0.2281 | 0.1804 | 0.1350 | | |
| 600 | 0.5090 | 0.4208 | 0.3495 | 0.2840 | 0.2310 | 0.1850 | 0.1420 | 0.0948 | |
| 800 | 0.5121 | 0.4232 | 0.3520 | 0.2861 | 0.2334 | 0.1896 | 0.1482 | 0.1028 | |
| 1000 | 0.5150 | 0.4260 | 0.3544 | 0.2880 | 0.2355 | 0.1939 | 0.1539 | 0.1100 | 0.0630 |
| 1250 | 0.5190 | 0.4297 | 0.3566 | 0.2906 | 0.2380 | 0.1975 | 0.1599 | 0.1179 | 0.0713 |
| 1500 | 0.5230 | 0.4330 | 0.3587 | 0.2919 | 0.2400 | 0.2010 | 0.1646 | 0.1252 | 0.0798 |
| 1750 | 0.5270 | 0.4366 | 0.3608 | 0.2949 | 0.2420 | 0.2040 | 0.1686 | 0.1319 | 0.0881 |
| 2000 | 0.5310 | 0.4400 | 0.3628 | 0.2965 | 0.2440 | 0.2083 | 0.1720 | 0.1370 | 0.0940 |
| 2200 | 0.5345 | 0.4433 | 0.3649 | 0.2990 | 0.2459 | 0.2060 | 0.1742 | 0.1400 | 0.0990 |
| 2500 | 0.5382 | 0.4470 | 0.3670 | 0.3010 | 0.2480 | 0.2098 | 0.1764 | 0.1430 | 0.1045 |
| 2750 | 0.5422 | 0.4502 | 0.3691 | 0.3024 | 0.2496 | 0.2110 | 0.1785 | 0.1444 | 0.1090 |
| 3000 | 0.5465 | 0.4535 | 0.3713 | 0.3042 | 0.2510 | 0.2127 | 0.1800 | 0.1470 | 0.1120 |
| 3500 | | 0.4593 | 0.3753 | 0.2070 | 0.2540 | 0.2151 | 0.1822 | 0.1510 | 0.1170 |
| 4000 | | 0.4655 | 0.3792 | 0.3095 | 0.2568 | 0.2183 | 0.1850 | 0.1532 | 0.1210 |
| 4500 | | 0.4714 | 0.3830 | 0.3118 | 0.2600 | 0.2200 | 0.1880 | 0.1555 | 0.1249 |
| 5000 | | 0.4782 | 0.3869 | 0.3145 | 0.2625 | 0.2229 | 0.1900 | 0.1579 | 0.1280 |

(Reference 5)

ABSOLUTE VISCOSITY —

centipoise
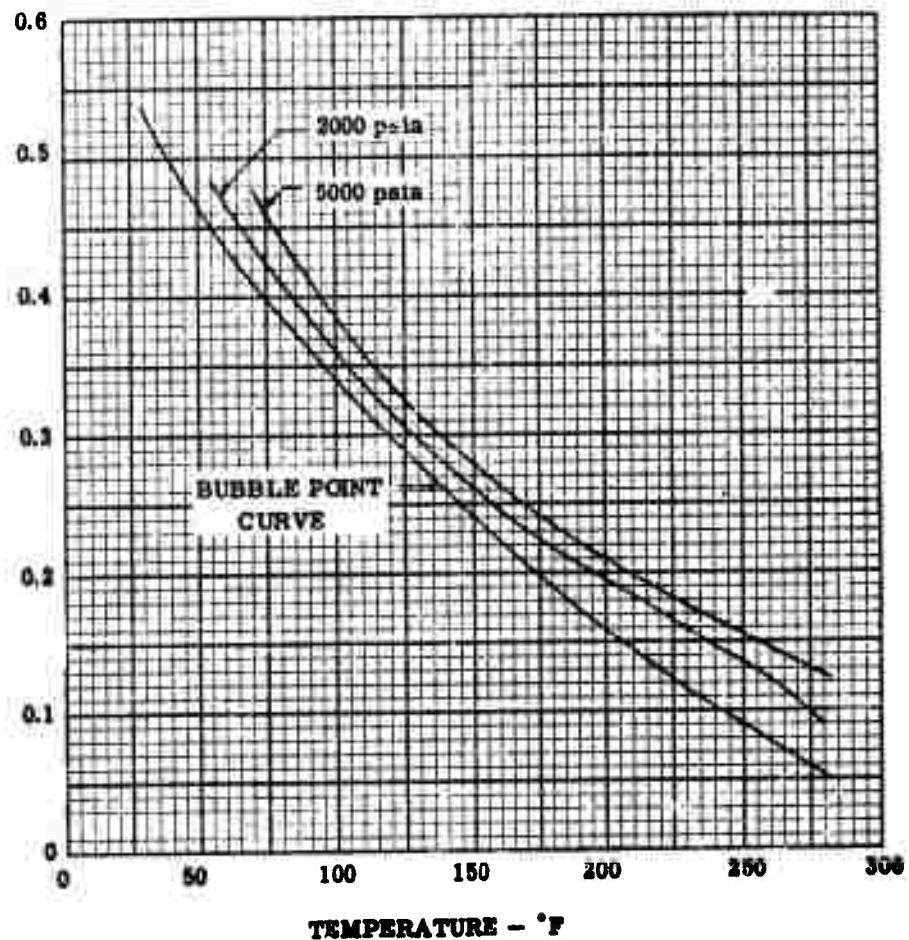


(Reference 5)

Figure 3.5. Effect of Temperature on Viscosity in the Liquid Phase, $N_2O_4$
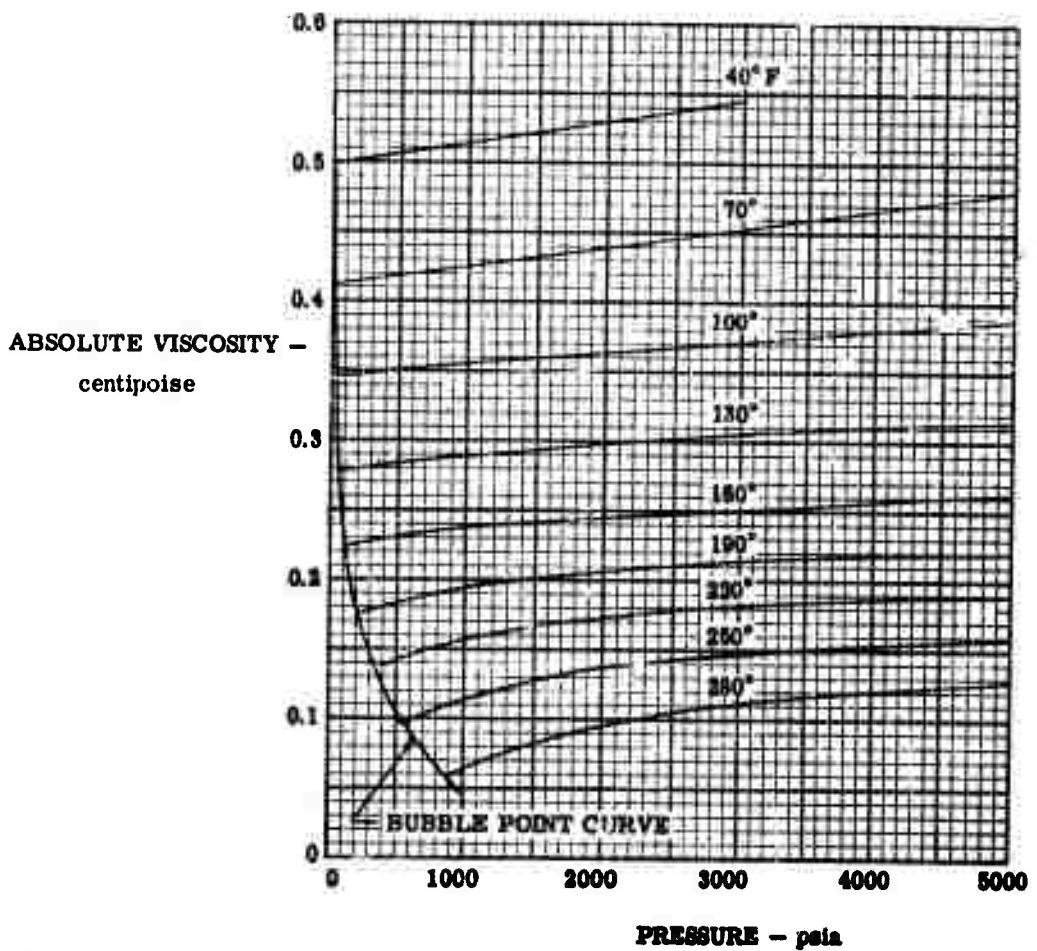
(Reference 5)

Figure 3.6. Effect of Pressure on Viscosity, Liquid $N_2O_4$

## 3.5 HEAT CAPACITY

Table 3.7 contains experimental heat capacity data for $N_2O_4$. Figure 3.7 is a plot of these points, as well as calculated points obtained by T.F. Morey (Reference 9).

### TABLE 3.7

### HEAT CAPACITY OF LIQUID $N_2O_4$

| Temperature ($^\circ$F) | Heat Capacity (BTU/lb-$^\circ$F) |
|---|---|
| 20.5 | 0.3564 |
| 27.0 | 0.3578 |
| 36.1 | 0.3598 |
| 48.6 | 0.3624 |
| 56.8 | 0.3652 |
| 64.8 | 0.3667 |

(Reference 8)
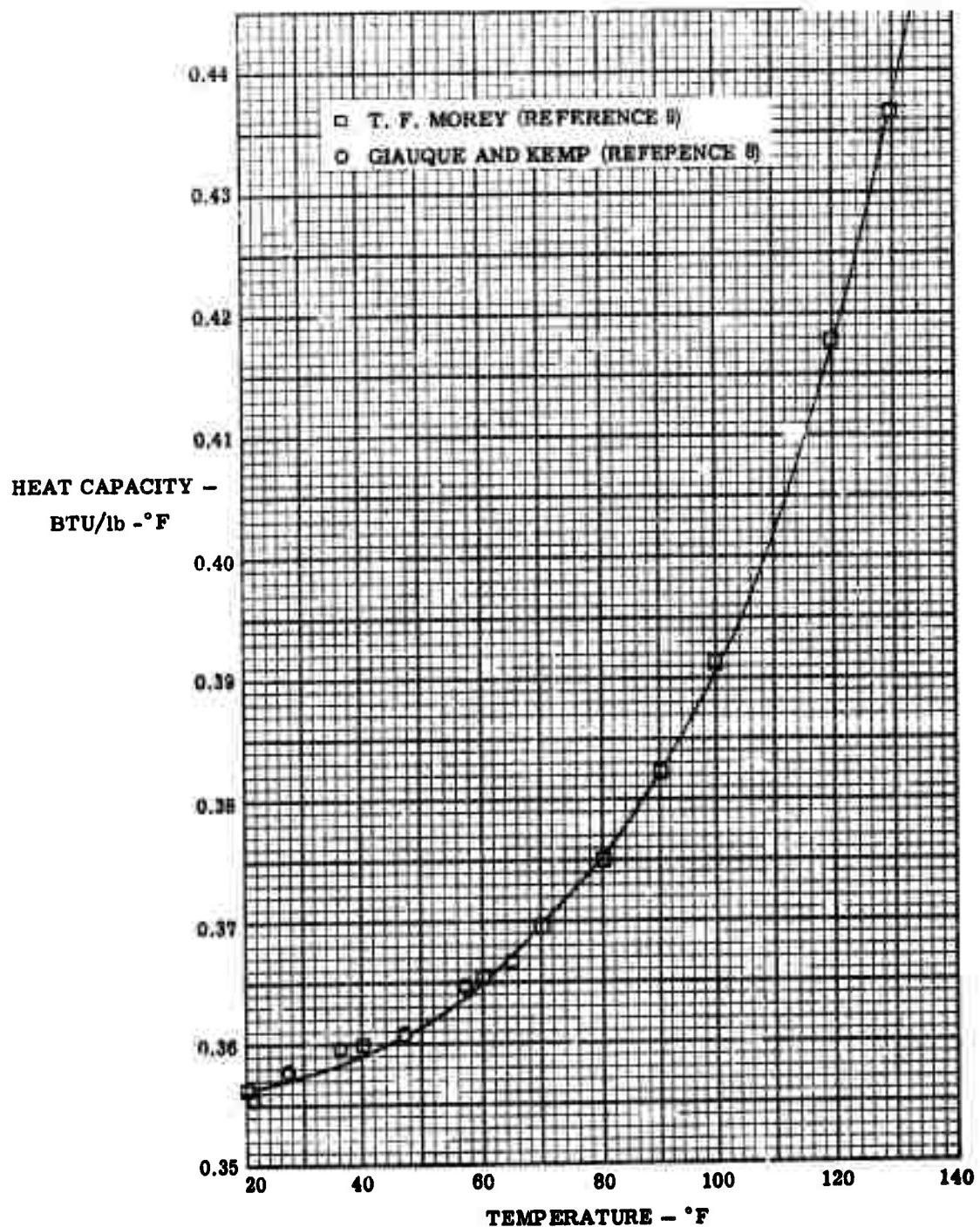
Figure 3.7. Heat Capacity of Liquid $N_2O_4$

## 3.6  SOLUBILITY OF PRESSURIZING GASES

The solubility of nitrogen and helium in $N_2O_4$ was determined using the apparatus shown in Reference 2 and the procedure described in Reference 3.  Results of these tests are presented in Table 3.8.

TABLE 3.8

### SOLUBILITY OF NITROGEN AND HELIUM IN LIQUID $N_2O_4$

| Pressurizing Gas | Temperature (°F) | Solubility (wt %) | Final Gas Pressure (psia) |
|---|---|---|---|
| Nitrogen | 70 | 0.20 ±0.01 | 63.7 |
| | 32 | 0.14 ±0.01 | 64.2 |
| Helium | 73 | 0.04 ±0.01 | 54.3 |
| | 32 | 0.02 ±0.01 | 55.4 |

(Reference 4)

# SECTION 4.0

## MATERIALS COMPATIBLITY, 50/50 FUEL BLEND

# SECTION 4.0

## MATERIALS COMPATIBILITY, 50/50 FUEL BLEND

### 4.1 EFFECTS OF FUEL BLEND ON METALS

As a result of laboratory tests interpreted on the basis of practical experience, the individual metals have been placed into four ratings similar to those used by the Defense Metals Information Center (Reference 17).

A: These metals are suitable for unrestricted use with the 50/50 fuel blend. Corrosion rates are less than 1 MPY. Typical uses are storage containers and valves where the propellant is in constant contact.

B: These metals are for restricted uses with the 50/50 fuel blend, such as transient or limited contact. The corrosion rates are a maximum of 5 MPY. Typical uses are for valves and lines on aerospace ground equipment, for hardware that contacts the propellant intermittently in the liquid and vapor phases, and for pumps and feed lines in which the residence time is limited to loading and unloading.

C: These metals have limited resistance and corrosion rates between 5 and 50 MPY. Typical use is where the metals are exposed to spillage and momentary contact, such as test stand hardware and aerospace ground equipment. These metals also have application where corrosion can be tolerated to the extent that it will not affect functional operations.

D: These metals are not recommended for use because their corrosion rates exceed 50 MPY and they cause propellant decomposition.

Table 4.1 contains pertinent compatibility data, references, and ratings for some metals and metal alloys exposed to the 50/50 fuel blend.

### 4.1.1 Aluminum Alloys

Aluminum alloys are protected from corrosion by naturally occurring oxide films on their surfaces. In certain alkali media like, 50/50 fuel blend, the aluminum alloy is highly resistant to attack. Often, the presence of foreign substances in the medium, rather than the degree of alka-

linity, is the controlling factor in the corrosion of aluminum alloys. The non-sparking tendencies of these alloys are desirable when handling explosive and flammable liquids.

The mechanical properties of the aluminum alloys are not affected by exposure to the 50/50 fuel blend (References 4, 10, and 11). There is no apparent correlation between the alloying constituents of the aluminum alloys and corrosion resistance in this fuel blend.

Welded 2014-T6 was given a "B" rating after exposure to fuel blend containing 3% water. Except for this case, the other aluminum alloys show excellent resistance to the 50/50 fuel blend. Rather than weight loss, most of these alloys experience slight weight gains after fuel exposure. Consideration is to be given to the proper cleaning and surface preparation of aluminum alloys to remove any heterogeneity on the surface resulting from fabrication techniques.

### 4.1.2 Stainless Steels

The fuel blend is a reducing agent and is slightly alkaline. From the standpoint of corrosion rate, the stainless steels are unaffected. Staining and minor deposits have been found in the vapor phase of 304L, 321, 347, 17-7 PH, 410, and 440C stainless steels which had not been acid-pickled prior to test (Reference 4). Acid-pickling remedies the deposit formation on the 300 series SS but does not for 410SS. Similar deposits are not found on PH 15-7 Mo, AM 355, and 316 stainless steel alloys which did not receive acid-pickling (Reference 4). Apparently, the existence of molybdenum in these alloys affords protection from the formation of deposits.

In general, the use of molybdenum-bearing stainless steel alloys with $N_2H_4$ are avoided; however, instances are cited in Reference 3 where Rocketdyne, Aerojet, JPL, and Bell Aerosystems have used alloys of this type with $N_2H_4$ without adverse incident. Testing of these stainless steel alloys with the fuel blend at 160°F for 90 days (Reference 4) resulted in an "A" rating for each alloy. Type 316 stainless steel was given an "A" rating when tested with the fuel blend containing up to 16% water.

### 4.1.3 Ferrous Alloys

Under ordinary temperatures, both moisture and oxygen are necessary for the corrosion of ferrous alloys in neutral or near-neutral media. Low concentrations of alkali have little to no effect on the corrosion of these alloys. Care should be exercised when using ferrous alloys because of the possible catalytic decomposition of the fuel blend due to rust.

Fuel blend spread on a rusted iron surface in contact with air may generate enough heat to cause spontaneous ignition. Experiments at Aerojet show that the probability of such reactions is low at ordinary ambient temperatures. Drops of fuel blend on heavily rusted surfaces in an air atmosphere at 150° to 160°F did not ignite (Reference 1).

Rust oxidizes $N_2H_4$ and may be a decomposition catalyst under certain conditions. Aerojet rapidly added a laboratory quantity of $N_2H_4$ to a few grams of ferric oxide at room temperature without any evidence of gross effects (Reference 1). However, if two to three drops of $N_2H_4$ are dropped onto a layer of ferric oxide spread on the bottom of a glass flask, ignition occurs in air at room temperature (Reference 44). The $N_2H_4$-air interface in the latter case is relatively large and the decomposition due to oxidation by both air and ferric oxide is so rapid that the $N_2H_4$ quickly ignites. In a nitrogen blanket, ignition did not occur until the nitrogen was replaced by air.

These experiments indicate that the surface area of the rust, the volume of liquid $N_2H_4$, and the presence of air are important factors in the rapid decomposition of $N_2H_4$. Vapors of $N_2H_4$ near 235°F are especially susceptible to explosive decomposition and metal oxides such as rust undoubtedly contribute to this reaction.

4.1.4   Nickel Alloys

In general, nickel and nickel alloys are corrosion resistant to the 50/50 fuel blend.

4.1.5   Titanium Alloys

Titanium alloys are resistant to 50/50 fuel blend corrosion. Titanium C120AV has been tested with the 50/50 fuel blend containing as much as 16% water without adverse effects.

4.1.6   Magnesium Alloys

Magnesium alloys show poor resistance to the 50/50 fuel blend.

4.1.7   Cobalt Alloys

Haynes Stellite 25, a cobalt-chrome alloy, exhibits good resistance to the fuel blend.

4.1.8   Copper Alloys

Berylco 25 darkens during exposure to the fuel blend, but exhibits good corrosion resistance. In general, copper alloys are recommended only for limited use with the fuel blend (Reference 15).

4.1.9   Platings

Gold-plated Berylco 25 darkens during exposure to the fuel blend, but exhibits good corrosion resistance. Non-porous chromium and nickel platings are satisfactory; electroless nickel is unsatisfactory for fuel blend service. Cadmium and silver plating are satisfactory for use with the fuel blend.

4.1.10  Conversion Coatings

Sulfuric acid anodize, Hardas (hardcoat) anodize, and iridite are the most resistant conversion coatings used on aluminum alloys. A simple fluoride coating on 2014-T6 aluminum is beneficial after exposure to the fuel blend (Reference 45).

4.1.11  Miscellaneous

Titanium carbide with a nickel binder is resistant to the fuel blend. Microseal 100-1 and 100-1CG graphite-ceramic type coatings on two magnesium alloys do not protect the alloys from corrosion.

TABLE 4.1

## COMPATIBILITY OF METALS WITH 50/50 FUEL BLEND

| MATERIAL | TEMPERATURE DEGREES FAHRENHEIT | STATIC EXPOSURE LIQUID | | | STATIC EXPOSURE VAPOR | | | STATIC EXPOSURE INTERFACE | | | REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | TIME IN DAYS | RATING[a] | REFERENCE | TIME IN DAYS | RATING[a] | REFERENCE | TIME IN DAYS | RATING[a] | REFERENCE | |
| **ALUMINUM ALLOYS** | | | | | | | | | | | |
| 1100 | 55-60 | 180 | A | 15 | | | | | | | |
| | 55-60 | 90 | A | 15 | | | | | | | 2% H₂O |
| **2014-T6 Sheet** | | | | | | | | | | | |
| Unwelded | 55-60 | 180 | A | 15 | 180 | A | 15 | 180 | A | 15 | |
| | 160 | 90 | A[b] | 4 | 90 | A[b] | 4 | 90 | A | 4 | Up to 16% H₂O, stain at interface and vapor phase |
| Welded | 55-60 | 180 | A | 15 | 180 | A | 15 | | | | 1% H₂O added |
| | 55-60 | 180 | B | 15 | | | | | | | 3% H₂O added |
| | 160 | 14 | A | 4 | | | | | | | Staining in vapor |
| Spotwelded | 55-60 | 180 | D | 15 | | | | | | | "D" rating because of cracks in heat affected zone |
| **2014-T6 Extrusion** | 160 | 90 | A[b] | 4 | 90 | A[b] | 4 | 90 | A | 4 | |
| Unwelded and stressed to 30,000 psi | 55-60 | 180 | A | 15 | | | | | | | |
| Welded and stressed to 30,000 psi | 55-60 | 180 | A | 15 | | | | | | | |
| 2024-T6 | 160 | 90 | A[b] | 4 | 90 | A[b] | 4 | 90 | A | 4 | |

a -- Definitions of ratings are given on page 4-1.
b -- Predicted rating from interface data.

TABLE 4.1 (CONT)

## COMPATIBILITY OF METALS WITH 50/50 FUEL BLEND

| MATERIAL | TEMPERATURE DEGREES FAHRENHEIT | STATIC EXPOSURE | | | | | | | | | REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | LIQUID | | | VAPOR | | | INTERFACE | | | |
| | | TIME IN DAYS | RATING[a] | REFERENCE | TIME IN DAYS | RATING[a] | REFERENCE | TIME IN DAYS | RATING[a] | REFERENCE | |
| ALUMINUM ALLOYS (CONT) | | | | | | | | | | | |
| 2219-T81 Welded and Unwelded | 55-60 | 180 | A | 15 | | | | | | | |
| 3003-H14 | 150 | | | | T | A | 14 | | | | |
| 5086-H36 | | | | | | | | | | | |
| Unwelded | 150 | 90 | A^b | 4 | 90 | A^b | 4 | 90 | A | 4 | |
| Welded | 150 | 14 | A | 4 | | | | | | | |
| 5254-F | 150 | 90 | A^b | 4 | 90 | A^b | 4 | 90 | A | 4 | Up to 10% H₂O discoloration in both phases |
| 5456-H24 | 55-60 | 180 | A | 15 | | | | | | | |
| 5456-H321 | 150 | 90 | A^b | 4 | 90 | A^b | 4 | 90 | A | 4 | |
| Unwelded | 55-60 | 90 | A | 15 | | | | | | | 5% H₂O |
| | 150 | 14 | A | 4 | | | | | | | |
| Stressed to 30,000 psi | 55-60 | 90 | A | 15 | | | | | | | 5% H₂O |
| Welded | 35-40 | 90 | A | 15 | 30 | A | 10 | | | | 5% H₂O |
| | 150 | 14 | A | 4 | | | | | | | |
| Stressed to 30,000 psi | 55-60 | 30 | A | 15 | | | | | | | 5% H₂O |
| 6061-T6 | | | | | | | | | | | |
| Unwelded | 55-60 | 180 | A | 15 | | | | | | | |
| | 150 | 14 | A | 4 | | | | | | | |

a — Definitions of ratings are given on page 4-1.
b — Predicted rating from interface data.

TABLE 4.1 (CONT)

COMPATIBILITY OF METALS WITH 50/50 FUEL BLEND

| MATERIAL | TEMPERATURE DEGREES FAHRENHEIT | | STATIC EXPOSURE | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | LIQUID | | | VAPOR | | | INTERFACE | |
| | | TIME IN DAYS | RATING[a] | REFERENCE | TIME IN DAYS | RATING[a] | REFERENCE | TIME IN DAYS | RATING[a] | REFERENCE | REMARKS |
| **ALUMINUM ALLOYS (CONT)** | | | | | | | | | | | |
| 6061-T6 | | | | | | | | | | | |
| Unwelded | 160 | 90 | A[b] | 4 | 90 | A[b] | 4 | 90 | A | 4 | Stain in interface, up to 16% $H_2O$ |
| Welded | 55-60 | 180 | A | 15 | | | | | | | |
| | 55-60 | 30 | A | 15 | | | | | | | 2% $H_2O$ |
| | 160 | 14 | A | 4 | | | | | | | |
| 6066 | 160 | 90 | A[b] | 4 | 90 | A[b] | 4 | 90 | A | 4 | |
| 7075-T6 | 55-60 | 90 | A | 15 | | | | | | | |
| | 160 | 90 | A[b] | 4 | 90 | A[b] | 4 | 90 | A | 4 | Multicoloration in vapor phase |
| Stressed to 80% yield | 55-60 | 30 | A | 15 | | | | | | | 2% $H_2O$ |
| 356 | 160 | 90 | A[b] | 4 | 90 | A[b] | 4 | 90 | A | 4 | Up to 16% $H_2O$, staining in vapor phase |
| | 55-60 | 90 | A | 15 | | | | | | | |
| Tens 50 | 160 | 90 | A[b] | 4 | 90 | A[b] | 4 | 90 | A | 4 | Staining in vapor |
| **STAINLESS STEELS** | | | | | | | | | | | |
| 303 | 160 | 90 | A[b] | 4 | 90 | A[b] | 4 | 90 | A | 4 | Stain in vapor |
| 304L | 55-60 | 180 | A | 15 | | | | | | | |
| | 160 | 14 | A | 4 | | | | | | | |
| | 160 | | | | | | | 90 | B | 4 | Deposits in vapor, up to 16% $H_2O$ |
| Welded | 180 | 14 | A | 4 | | | | | | | |

a — Definitions of ratings are given on page 4-1.
b — Predicted rating from interface data.

TABLE 4.1 (CONT)

COMPATIBILITY OF METALS WITH 50/50 FUEL BLEND

| MATERIAL | TEMPERATURE DEGREES FAHRENHEIT | STATIC EXPOSURE | | | | | | | | | REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | LIQUID | | | VAPOR | | | INTERFACE | | | |
| | | TIME IN DAYS | RATING a | REFERENCE | TIME IN DAYS | RATING a | REFERENCE | TIME IN DAYS | RATING a | REFERENCE | |
| **STAINLESS STEELS (CONT)** | | | | | | | | | | | |
| 316 | 160 | 90 | $A^b$ | 4 | 90 | $A^b$ | 4 | 90 | A | 4 | Stains in vapor, up to 1.0% H₂O |
| 321 | 160 | | | | | | | 90 | B | 4 | Deposits in vapor |
| | 160 | 14 | A | 4 | | | | | | | Stains in vapor |
| Welded | 160 | 14 | A | 4 | | | | | | | Stains in vapor |
| | 55-60 | 180 | A | 15 | | | | | | | |
| 347 | 160 | | | | | | | 90 | B | 4 | Deposits in vapor |
| | 160 | 14 | A | 4 | | | | | | | |
| Welded | 55-60 | 180 | A | 15 | 180 | A | 15 | 180 | A | 15 | |
| | 160 | 14 | A | 4 | | | | | | | |
| PH 15-7 Mo Cond. A | 160 | 90 | $A^b$ | 4 | 90 | $A^b$ | 4 | 90 | A | 4 | Stain in vapor; no deposits |
| 17-4 PH | 160 | 90 | $A^b$ | 4 | 90 | $A^b$ | 4 | 90 | A | 4 | Stain in vapor; no deposits |
| 17-7 PH Cond. A | 160 | | | | | | | 90 | B | 4 | Deposits in vapor |
| AM 355 Cond. H | 160 | 180 | $A^b$ | 4 | 180 | $A^b$ | 4 | 180 | A | 4 | Stain in vapor; no deposits |
| 410 H & T | 160 | | | | | | | 90 | B | 4 | Deposits in vapor |
| Welded | 160 | 14 | B | 4 | | | | | | | Deposits in vapor |
| 440 C | 160 | | | | | | | 90 | B | 4 | Deposits in vapor |

a — Definitions of ratings are given on page 4-1.
b — Predicted rating from interface data.

## TABLE 4.1 (CONT)

## COMPATIBILITY OF METALS WITH 50/50 FUEL BLEND

| MATERIAL | TEMPERATURE DEGREES FAHRENHEIT | STATIC EXPOSURE LIQUID | | | VAPOR | | | INTERFACE | | | REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | TIME IN DAYS[a] | RATING[a] | REFERENCE | TIME IN DAYS[a] | RATING[a] | REFERENCE | TIME IN DAYS[a] | RATING[a] | REFERENCE | |
| **FERROUS ALLOYS** | | | | | | | | | | | |
| 1020 | 55-60 | 180 | C | 15 | | | | | | | These would have an "A" rating except for their susceptibility to rusting |
| 4130 | 55-60 | 180 | C | 15 | | | | | | | |
| A 386 | 55-60 | 150 | C | 15 | | | | | | | |
| **NICKEL ALLOYS** | | | | | | | | | | | |
| Nickel | 150 | 90 | A[b] | 4 | 90 | A[b] | 4 | 90 | A | 4 | |
| Nilvar | 55-60 | 100 | A | 15 | | | | | | | |
| Ni Span C | 55-60 | 30 | A | 15 | | | | | | | 3% H$_2$O |
| **TITANIUM ALLOYS** | | | | | | | | | | | |
| B120 VCA | 55-60 | 180 | A | 15 | | | | | | | |
| | 160 | 90 | A[b] | 4 | 90 | A[b] | 4 | 90 | A | 4 | |
| A110-AT | 160 | 90 | A[b] | 4 | 90 | A[b] | 4 | 90 | A | 4 | |
| C130 AV | 55-60 | 30 | A | 15 | | | | | | | 3% H$_2$O |
| | 160 | 90 | A[b] | 4 | 90 | A[b] | 4 | 90 | A | 4 | Up to 10% H$_2$O |
| **MAGNESIUM ALLOYS** | | | | | | | | | | | |
| HM21A-T8 | 55-60 | 30 | D | 15 | | | | | | | Pitted |
| **COBALT ALLOYS** | | | | | | | | | | | |
| Haynes Stellite 25 | 160 | 90 | A[b] | 4 | 90 | A[b] | 4 | 90 | A | 4 | |

a — Definitions of ratings are given on page 4-1.
b — Predicted rating from interface data.

## TABLE 4.1 (CONT)

## COMPATIBILITY OF METALS WITH 50/50 FUEL BLEND

| MATERIAL | TEMPERATURE DEGREES FAHRENHEIT | TIME IN DAYS | RATING[a] | STATIC EXPOSURE LIQUID REFERENCE | TIME IN DAYS | RATING[a] | VAPOR REFERENCE | TIME IN DAYS | RATING[a] | INTERFACE REFERENCE | REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **COPPER ALLOYS** | | | | | | | | | | | |
| Berylco 25 | 160 | 90 | A[b] | 4 | 90 | A[b] | 4 | 90 | A | 4 | Darkened |
| **PLATINGS** | | | | | | | | | | | |
| Cadmium | 55-60 | - | C | 15 | | | | | | | |
| Chromium (non-porous) | 55-60 | - | A | 15 | | | | | | | |
| Copper | 55-60 | - | C | 15 | | | | | | | |
| Gold on Berylco 25 | 160 | 90 | A[b] | 4 | 90 | A[b] | 4 | 90 | A | 4 | Darkened |
| Nickel Electrolytic (non-porous) | 55-60 | - | A | 15 | | | | | | | |
| Electroless | 55-60 | - | D | 15 | | | | | | | |
| Silver | 55-60 | - | D | 15 | | | | | | | |
| Tin | 55-60 | - | D | 15 | | | | | | | |
| Zinc | 55-60 | - | D | 15 | | | | | | | |
| **COATINGS ON ALUMINUM ALLOYS** | | | | | | | | | | | |
| Iridite 2014-T6 | 55-60 | 180 | A | 15 | | | | | | | |
| Alodine 2014-T6 | 160 | | | | | | | 90 | B | 4 | Lost weight; stain at interface; up to 16% $H_2O$ |
| 6061-T6 | 160 | 90 | A[b] | 4 | 90 | A[b] | 4 | 90 | A | 4 | Gained weight; up to 16% $H_2O$ |
| Hardas (Hardcoat) Anodize 2014-T6 | 55-60 | 180 | A | 15 | | | | | | | |

a — Definitions of ratings are given on page 4-1.
b — Predicted rating from interface data.

## TABLE 4.1 (CONT)

## COMPATIBILITY OF METALS WITH 50/50 FUEL BLEND

| MATERIAL | TEMPERATURE DEGREES FAHRENHEIT | STATIC EXPOSURE | | | | | | | | | REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | LIQUID | | | VAPOR | | | INTERFACE | | | |
| | | TIME IN DAYS | RATING[a] | REFERENCE | TIME IN DAYS | RATING[a] | REFERENCE | TIME IN DAYS | RATING[a] | REFERENCE | |
| COATINGS ON ALUMINUM ALLOYS (CONT) | | | | | | | | | | | |
| Sulfuric Acid Anodize 2014-T6 | 160 | 90 | A[b] | 4 | 90 | A[b] | 4 | 90 | A | 4 | Lost weight; up to 16% $H_2O$; no deposit; some stain |
| 6061-T6 | 160 | 90 | A[b] | 4 | 90 | A[b] | 4 | 90 | A | 4 | Gained weight; up to 16% $H_2O$; stain at interface |
| Fluoride 2014-T6 | 70-80 | 9 | A | 45 | | | | | | | "A" rating based on visual examination |
| MISCELLANEOUS | | | | | | | | | | | |
| Titanium Carbide with Nickel Binder | 160 | 90 | A[b] | 4 | 90 | A[b] | 4 | 90 | A | 4 | |
| Silver Solder | 55-60 | 180 | A | 15 | | | | | | | |
| Microseal 100-1 coating on AM 100A Magnesium | 160 | | | | | | | 90 | D | 4 | Coating porous metal attacked |
| Microseal 100-1 CG Coating on AZ 31 C Magnesium | 160 | | | | | | | 3 | D | 4 | Coating porous, metal attacked |

a — Definitions of ratings are given on page 4-1.
b — Predicted rating from interface data.

### TABLE 4.1 (CONT)

### COMPATIBILITY OF METALS WITH 50/50 FUEL BLEND

| MATERIAL | TEMPERATURE DEGREES FAHRENHEIT | TIME IN DAYS | RATING[a] | REFERENCE | TIME IN DAYS | RATING[a] | REFERENCE | TIME IN DAYS | RATING[a] | REFERENCE | REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **BRAZING AND SOLDERING** | | | | | | | | | | | |
| 6061-T6 Al Brazed with 718 Filler | 160 | 14 | A | 4 | | | | | | | |
| 303 SS Soldered with Pure Tin | 165 | 14 | A | 4 | | | | | | | Tin solder darkened |
| 347 Silver Brazed with Easy Flo per QQS-561 Class 4 | 160 | 14 | A | 4 | | | | | | | |
| 347 SS Nicrobrazed AMS 4775 | 160 | 14 | A | 4 | | | | | | | Stain in vapor |
| **METAL COUPLES** | | | | | | | | | | | |
| 2014-T6 Al Bolted to 321 SS | 55-50 | 90 | A | 15 | 180 | A | 15 | 120 | A | 15 | |
| 2014-T6 Al Bolted to 6Al + 4V Titanium | 55-60 | 90 | A | 15 | | | | | | | |
| 2014-T6 Al Welded to 6061-T6 Al | 160 | 14 | A | 4 | | | | | | | |
| 6061-T6 Al Ultrasonic Welded to 321 SS | 55-60 | 30 | D | 15 | | | | | | | "D" rating because of visible cracks in area of poor fusion |

a — Definitions of ratings are given on page 4-1.

## TABLE 4.1 (CONT)

## COMPATIBILITY OF METALS WITH 50/50 FUEL BLEND

| MATERIAL | TEMPERATURE DEGREES FAHRENHEIT | STATIC EXPOSURE | | | | | | | | | REMARKS |
| | | LIQUID | | | VAPOR | | | INTERFACE | | | |
| | | TIME IN DAYS | RATING[a] | REFERENCE | TIME IN DAYS | RATING[a] | REFERENCE | TIME IN DAYS | RATING[a] | REFERENCE | |
| METAL COUPLES (CONT) 6061-T6 Al Spotwelded to 2014-T6 Al | 55-60 | 90 | D | 15 | | | | | | | 2% H-O, "D" rating because of weld cracks |

a — Definitions of ratings are given on page 4-1.

## 4.2 EFFECTS OF FUEL BLEND ON NONMETALS

Government specifications[a] on rubbers and plastic fabricated parts intended for packings and seals show that the physical property effects to be minimized are volume change, durometer change, effect on media, and visual examination in terms of surface appearance. The specifications contain different values for volume change and durometer change. Using the ranges called for in the specifications, the following ratings were derived for the nonmetals:

|  | A | B | C | D |
|---|---|---|---|---|
| Volume Change, % | 0 to +25 | -10 to +25 | -10 to +25 | $<$-10 or$>$+25 |
| Durometer Reading Change | ±3 | ±10 | ±10 | $<$-10 or$>$+10 |
| Effect on Propellant | None | None | Slight Change | Severe |
| Visual Examination | No Change | No Change | Slight Change | Dissolved, severely blistered or cracked |

Definitions for these ratings are as follows:

A: Satisfactory for service under conditions indicated.

B: Use with knowledge that it will swell or shrink and/or change in hardness.

C: Satisfactory for ground support where preventative maintenance can be scheduled. Also good for actual missile service where slight discoloration of propellant and extracted residue is tolerable.

D: Unsatisfactory for use.

Table 4.2 contains compatibility data, references, and ratings for several nonmetals exposed to the 50/50 fuel blend.

The fuel blend can dissolve, attack, or decompose nonmetals such as plastics, elastomers, lubricants, and coatings. These reactions usually cause degradation or complete destruction of the material. The fuel can extract components from the material or be absorbed by the material, thereby altering the physical properties. The nonmetals investigated embrace a wide variety of

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a—Government Specifications:

| MIL-R-2765A | Rubber, Synthetic, Oil Resistant (Sheet, Strip, and Molded Shapes). |
| MIL-R-3065B | Rubber Fabricated Parts. |
| MIL-R-8791A | Retainer Packing, Hydraulic and Pneumatic, Tetrafluorethylene. |
| HH-P-131C | Packing, Metallic and Nonmetallic, Plastic. |
| HH-P-166A | Packing, Nonmetallic. |

chemical and physical structures; as such, methods of fabrication and geometrical factors greatly influence the behavior of the material.

For example, many materials can be used as gaskets or seals where a definite compression set limitation, and in all probability a volume change limitation, is required for sealing. The gasket or seal can be enclosed between two metal surfaces with only a small portion exposed to the fuel. The swelling characteristics of this type exposure are of less importance than the swelling obtained from complete immersion in the fuel where volume change is magnified. Tensile properties play a small role in the application of a material as a gasket. For this reason, use of the nonmetals must be weighed in terms of the physical properties desired.

### 4.2.1 Plastics

Teflon and Teflon products are chemically resistant to the 50/50 fuel blend.

Nylons 31, 63, and 101 vary in composition and are highly inert to most solvents; however, their resistance to the 50/50 fuel blend is limited to 90 to 120 days at 70° to 80°F (References 1 and 15). At 160°F, the nylons failed within 30 days (Reference 4).

The polyethylenes have fair resistance to solvents and have a limited use temperature range. In the 50/50 fuel blend, they are subject to stress cracking (Reference 1). The irradiated polyethylene is the most resistant. Kel-F 300 shows cracking tendency (Reference 1) after 70 days at 70° to 80°F and darkens and becomes brittle within 30 days at 160°F (Reference 4).

### 4.2.2 Elastomers

Butyl rubbers are characterized by good resistance to aging and superior properties over natural rubbers. They are compounded to attain desirable properties. Most butyl rubbers exhibit good resistance to the 50/50 fuel blend.

The fluorosilicones characterized by good heat resistance and fair resistance to solvents show poor resistance to the fuel blend. This is also true of the fluororubbers.

### 4.2.3 Lubricants and Sealants

All lubricants except Microseal 100-1 dissolve or wash out to varying degrees when exposed to the 50/50 fuel blend. The UDMH Lube is the most satisfactory based upon service and dynamic tests performed on an O-ring (Reference 4). Lox Safe, ANDOK-C, and S#58-M oil show promise and could be considered for service. Reddy Lubes 100 and 200 and water glass/graphite blend are satisfactory sealants with the fuel blend.

4.2.4   Potting Compounds and Ceramics

Only Crystal M & CF, a potting compound, is satisfactory for limited use with the fuel blend. Temporell, Sauereisen P-1 and 31, and Rockflux are ceramics satisfactory for service with the fuel blend.

4.2.5   Adhesives

Armstrong A-6 and HT 424 are adhesives reported satisfactory for service with the fuel blend.

4.2.6   Paints

Tests to date indicate that no paints are compatible with the fuel blend.

TABLE 4.2

COMPATIBILITY OF NONMETALS WITH 50/50 FUEL BLEND

| MATERIAL | TEMPERATURE DEGREES FAHRENHEIT | STATIC EXPOSURE LIQUID | | | VAPOR | | | REMARKS |
|---|---|---|---|---|---|---|---|---|
| | | TIME IN DAYS | RATING[a] | REFERENCE | TIME IN DAYS | RATING[a] | REFERENCE | |
| **PLASTICS** | | | | | | | | |
| Polytetra-fluorethylene | | | | | | | | |
| Teflon (TFE) | 55-60 | 130 | A | 15 | | | | Up to 3% H$_2$O |
| | 70-80 | 135 | A | 1 | | | | |
| | 180 | 30 | B | 4 | | | | Shrinks 4.5%, 7% tensile loss |
| Teflon filled with graphite | 55-60 | 180 | A | 15 | | | | 3% H$_2$O |
| Teflon filled with molydisulfide | 55-60 | 180 | A | 15 | | | | 3% H$_2$O |
| Teflon filled with asbestos | 55-80 | 90 | A | 15 | | | | 3% H$_2$O |
| Armalon 7700 impregnated with Teflon fibers | 55-60 | 90 | C | 15 | | | | 3% H$_2$O, fuel discolored |
| Armalon 7700B impregnated with Teflon fibers | 55-90 | 90 | A | 15 | | | | 3% H$_2$O |
| Fluorobestos filled with asbestos | 55-60 | 90 | A | 15 | | | | 3% H$_2$O |
| TFE-felt 7550 | 55-60 | 90 | C | 15 | | | | 3% H$_2$O, fuel discolored |

a — Definitions of ratings are given on page 4-14.

TABLE 4.2 (CONT)

COMPATIBILITY OF NONMETALS WITH 50/50 FUEL BLEND

| MATERIAL | TEMPERATURE DEGREES FAHRENHEIT | | | STATIC EXPOSURE | | | | REMARKS |
|---|---|---|---|---|---|---|---|---|
| | | TIME IN DAYS | RATING[a] | LIQUID REFERENCE | TIME IN DAYS | RATING[a] | VAPOR REFERENCE | |
| PLASTICS (CONT) | | | | | | | | |
| Fluorinated Propylene Co-polymer | | | | | | | | |
| Teflon (FEP) | 55-60 | 180 | A | 15 | | | | Up to 3% $H_2O$ |
| | 70-80 | 60 | A | 1 | | | | |
| | 160 | 30 | B | 4 | | | | Shrinks 15.6% |
| Polychloro-trifluoro-ethylene | | | | | | | | |
| Kel-F 300 Unplasti-cized | 55-60 | 180 | A | 15 | | | | Up to 3% $H_2O$ |
| | 70-80 | 70 | B | 1 | | | | Hardened, cracking tendency |
| | 160 | 30 | D | 4 | | | | Blackened, became fragile |
| Kel-F Annealed | 55-60 | 90 | A | 15 | | | | 2% $H_2O$ |
| Polyethylene | | | | | | | | |
| Low Density | 55-60 | 30 | A | 11 | | | | |
| Hi Density | 160 | 30 | C | 4 | | | | Shrinks 10.6% |
| Marlex 50 Hi Density | 55-60 | 90 | B | 15 | | | | 2% $H_2O$, shrinks 2.2% |
| Polyolefin | | | | | | | | |
| White insu-lation | 160 | 30 | A | 4 | | | | |
| Black insu-lation | 160 | 30 | C | 4 | | | | Fuel discolored |

a — Definitions of ratings are given on page 4-14.

TABLE 4.2 (CONT)

COMPATIBILITY OF NONMETALS WITH 50/50 FUEL BLEND

| MATERIAL | TEMPERATURE DEGREES FAHRENHEIT | STATIC EXPOSURE | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | LIQUID | | | VAPOR | | | |
| | | TIME IN DAYS | RATING[a] | REFERENCE | TIME IN DAYS | RATING[a] | REFERENCE | REMARKS |
| PLASTICS (CONT) | | | | | | | | |
| Polypropylene | | | | | | | | |
| From Hercules | 55-60 | 90 | A | 10 | | | | |
| From Chicago Molded Products | 160 | 30 | A | 4 | | | | 0.1% tensile loss |
| Polyamide-Nylon | | | | | | | | |
| Zytel 31 | 70-80 | 110 | A | 1 | | | | |
| | 160 | 7 | D | 4 | | | | Crumbled |
| Zytel 63 | 70-80 | - | D | 1 | | | | Dissolved |
| Zytel 101 | 55-60 | 180 | D | 15 | | | | 2% $H_2O$, disintegrating |
| | 70-80 | 120 | B | 1 | | | | Softened 17% |
| | 160 | 7 | D | 4 | | | | Crumbled |
| Polyester | | | | | | | | |
| Mylar | 55-60 | 30 | D | 11 | | | | Dissolved |
| Laminates-Glass | | | | | | | | |
| Silicone (composition unknown) | 55-60 | 180 | C | 15 | | | | Partially delaminated |
| Phenolic (composition unknown) | 55-60 | 180 | C | 15 | | | | Fuel discolored, partially delaminated |
| Epoxy (composition unknown) | 55-60 | 180 | D | 15 | | | | Delaminated |

a — Definitions of ratings are given on page 4-14.

TABLE 4.2 (CONT)

COMPATIBILITY OF NONMETALS WITH 50/50 FUEL BLEND

| MATERIAL | TEMPERATURE DEGREES FAHRENHEIT | STATIC EXPOSURE | | | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| | | LIQUID | | | VAPOR | | | |
| | | TIME IN DAYS | RATING[a] | REFERENCE | TIME IN DAYS | RATING[a] | REFERENCE | REMARKS |
| PLASTICS (CONT) | | | | | | | | |
| Polyester (composition unknown) | 55-60 | 30 | D | 11 | | | | Delaminated |
| Polyvinylidene Chloride | | | | | | | | |
| Saran | 55-60 | 30 | D | 15 | | | | |
| Polyformaldehyde | | | | | | | | |
| Delrin | 55-60 | 90 | D | 10 | | | | Shrinks 20%, increased in hardness 23% |
| Polycarbonate | | | | | | | | |
| Lexan | 55-60 | 30 | D | 11 | | | | Dissolved |
| Polyvinyl Fluoride | | | | | | | | |
| Teslar | 55-60 | 30 | B | 11 | | | | Shrinks 4.4% |
| Polymethyl Methacrylate | | | | | | | | |
| Plexiglass | 55-60 | 90 | D | 15 | | | | Cracking and dissolving |
| BUTYL RUBBERS | | | | | | | | |
| Parco 823-70 | 70-80 | 142 | B | 1 | | | | Softened 30% |
| Precision Rubber 9257, 9357 | 70-80 | 50 | B | 1 | | | | Softened 15% |

a — Definitions of ratings are given on page 4-14.

TABLE 4.2 (CONT)

COMPATIBILITY OF NONMETALS WITH 50/50 FUEL BLEND

| MATERIAL | TEMPERATURE DEGREES FAHRENHEIT | STATIC EXPOSURE | | | | | | REMARKS |
|---|---|---|---|---|---|---|---|---|
| | | LIQUID | | | VAPOR | | | |
| | | TIME IN DAYS | RATING[a] | REFERENCE | TIME IN DAYS | RATING[a] | REFERENCE | |
| **BUTYL RUBBERS (CONT)** | | | | | | | | |
| Parker B480-7 | 70-80 | 162 | D | 1 | | | | Softened 20% |
| Parco 805-70 | 70-80 | 68 | D | 1 | | | | Softened 37%, fuel discolored amber |
| | 160 | 30 | C | 4 | | | | Precipitate extracted, tensile loss 28.8% |
| Goshen 1357 | 70-80 | 68 | D | 1 | | | | Softened 12%, fuel discolored amber |
| | 160 | 30 | C | 4 | | | | Precipitate extracted, tensile loss 28.5% |
| Enjay 268 | 55-60 | 30 | C | 15 | | | | Fuel discolored yellow |
| Enjay 551 | 55-60 | 30 | C | 15 | | | | Fuel discolored yellow |
| Precision 214-907-9 | 160 | 1 | D | 4 | | | | Violent reaction - compound similar to Enjay 62790 |
| | 70-80 | 7 | - | 4 | | | | No violent reaction |
| Hycar 2202 | 55-60 | 30 | D | 11 | | | | 43%, fuel yellow |
| Linear 7806-70 | 160 | 30 | D | 4 | | | | Precipitate extracted, cracked |
| Parker XB800-71 | 160 | 30 | A | 4 | | | | Tensile loss 6.8% |
| Parker B496-7 | 160 | 30 | A | 4 | | | | Tensile loss 11.4% |
| Parker 318-70 | 160 | 30 | C | 4 | | | | Precipitate extracted, tensile loss 29.7% |

a — Definitions of ratings are given on page 4-14.

TABLE 4.2 (CONT)

COMPATIBILITY OF NONMETALS WITH 50/50 FUEL BLEND

| MATERIAL | TEMPERATURE DEGREES FAHRENHEIT | STATIC EXPOSURE | | | | | | REMARKS |
|---|---|---|---|---|---|---|---|---|
| | | LIQUID | | | VAPOR | | | |
| | | TIME IN DAYS | RATING[a] | REFERENCE | TIME IN DAYS | RATING[a] | REFERENCE | |
| BUTYL RUBBERS (CONT) | | | | | | | | |
| Stillman 613-75 | 160 | 30 | C | 4 | | | | Precipitate extracted, tensile loss 10% |
| | 70-80 | 540 | B | 21 | | | | Softened |
| POLYBUTA-DIENE RUB-BERS | | | | | | | | |
| Acushnet | | | | | | | | |
| SWK 422 | 160 | 30 | C | 4 | | | | Precipitate extracted, tensile loss 8.3% |
| SWK 848 | 160 | 30 | C | 4 | | | | Precipitate extracted, tensile loss 41.9% |
| SWK 850 | 160 | 30 | C | 4 | | | | Precipitate extracted, tensile loss 33.6% |
| SWK 851 | 160 | 30 | C | 4 | | | | Slight precipitate extracted, no strength loss; these are similar to Phillips compound No. 4706 |
| Stillman EX 904-90 (Hydropol) | 160 | 30 | D | 4 | | | | 29% volume swell, tensile loss 77.9%, brittle |
| FLUOROSIL-ICONE RUB-BERS | | | | | | | | |
| LS 53 | 55-60 | 30 | D | 15 | | | | Decomposed |
| Raybar 58T89-33GT | 160 | 30 | C | 4 | | | | Precipitate extracted, tensile loss 73.5% |

a — Definitions of ratings are given on page 4-14.

TABLE 4.2  (CONT)

COMPATIBILITY OF NONMETALS WITH 50/50 FUEL BLEND

| MATERIAL | TEMPERATURE DEGREES FAHRENHEIT | STATIC EXPOSURE LIQUID TIME IN DAYS | RATING[a] | REFERENCE | STATIC EXPOSURE VAPOR TIME IN DAYS | RATING[a] | REFERENCE | REMARKS |
|---|---|---|---|---|---|---|---|---|
| **FLUORO RUBBERS** | | | | | | | | |
| Viton A | 55-60 | 30 | D | 11 | | | | Decomposed |
| Viton B | 55-60 | 30 | D | 11 | | | | Dissolved |
| Kel-F Elastomer | 55-60 | 30 | D | 11 | | | | Dissolved |
| Fluorel | 55-60 | 30 | D | 15 | | | | |
| **MISCELLA- NEOUS RUBBERS** | | | | | | | | |
| Garlock 900 | 55-60 | 90 | D | 10 | | | | Fuel yellow, crystals on specimen |
| Garlock 22 | 55-60 | 90 | C | 10 | | | | Fuel discolored yellow |
| Buna N | 55-60 | 30 | D | 11 | | | | Sample blistered |
| Neoprene | 55-60 | 90 | D | 10 | | | | Fuel discolored red, softened 25% |
| Cohrlastic 600 | 55-60 | 90 | D | 10 | | | | Hardened |
| Hypalon 30 | 55-60 | 90 | D | 10 | | | | Black particles in fuel |
| **LUBRICANTS** | | | | | | | | |
| UDMH Lube | 70-80 | 1[b] | C | 4 | | | | Some washed off |
| 3 #55-M | 70-80 | 1[b] | C | 4 | | | | Some washed off |
| Lox Safe | 70-80 | 1[b] | C | 4 | | | | Some washed off |
| ANDOK-C | 70-90 | 1[b] | C | 4 | | | | Some washed off |

a — Definitions of ratings are given on page 4-14.
b — Dynamic tests with Parco 805-70 butyl rubber O-rings.

TABLE 4.2 (CONT)

COMPATIBILITY OF NONMETALS WITH 50/50 FUEL BLEND

| MATERIAL | TEMPERATURE DEGREES FAHRENHEIT | STATIC EXPOSURE | | | | | | REMARKS |
|---|---|---|---|---|---|---|---|---|
| | | LIQUID | | | VAPOR | | | |
| | | TIME IN DAYS | RATING [a] | REFERENCE | TIME IN DAYS | RATING [a] | REFERENCE | |
| **LUBRICANTS (CONT)** | | | | | | | | |
| DC-11 | 70-80 | 1 [b] | C | 4 | | | | Some washed off |
| | 70-80 | 14 | C | 4 | 14 | C | 4 | Washed off in liquid, partly in vapor |
| Microseal 100-1 (dry lube) | 70-80 | 1 [b] | B | 4 | | | | Compatible |
| Rockwell Nordstrom 960 | 70-80 | 1 [b] | C | 4 | | | | Some washed off |
| DC-55 | 70-80 | 1 [b] | C | 4 | | | | May affect butyl rubber |
| | 70-80 | 14 | C | 4 | 14 | C | 4 | Washed off in liquid, partly in vapor |
| DC-Hi Vacuum | 70-80 | 1 [b] | C | 4 | | | | May affect O-ring |
| | 55-60 | 90 | C | 10 | | | | Some washed off |
| | 70-80 | 14 | C | 4 | 14 | C | 4 | Washed off in liquid, partly in vapor |
| Kel-F 90 | 55-60 | 90 | D | 11 | | | | Reacted |
| Molykote Z | 55-60 | 90 | D | 11 | | | | Reacted and evolved gas |
| Drilube 703 | 55-60 | 90 | D | 11 | | | | Gas evolved |
| Rayco-37 | 55-60 | 90 | D | 11 | | | | Decomposed |
| QC-2-0036 QC-2-0063 | 55-60 | 90 | D | 11 | | | | Dissolved |
| Electrofilm 66-C | 55-60 | 90 | D | 11 | | | | Swollen |

a — Definitions of ratings are given on page 4-14.
b — Dynamic tests with Parco 805-70 butyl rubber O-rings.

TABLE 4.2 (CONT)

COMPATIBILITY OF NONMETALS WITH 50/50 FUEL BLEND

| MATERIAL | TEMPERATURE DEGREES FAHRENHEIT | STATIC EXPOSURE | | | | | |
|---|---|---|---|---|---|---|---|
| | | LIQUID | | | VAPOR | | |
| | | TIME IN DAYS | RATING[a] | REFERENCE | TIME IN DAYS | RATING[a] | REFERENCE | REMARKS |
| **LUBRICANTS (CONT)** | | | | | | | | |
| TMEF-1,2,3 | 55-60 | 30 | D | 11 | | | | Broken up |
| Polyglycol Oils | 70-90 | 14 | C | 1,4 | | | | Some washed off |
| L-1111 | 70-90 | 14 | D | 4 | | | | 2 phases, fuel turned orange |
| **THREAD SEALANTS** | | | | | | | | |
| Reddy Lube | | | | | | | | |
| 100 | 70-90 | 14 | A | 4 | | | | Satisfactory |
| 200 | 70-90 | 14 | A | 4 | | | | Satisfactory |
| Water Glass-Graphite | 70-90 | 14 | A | 4 | | | | Satisfactory |
| Vydax A | 70-90 | 14 | C | 4 | | | | Some washed off |
| **POTTING COMPOUNDS** | | | | | | | | |
| PR 1422 | 55-60 | 30 | D | 11 | | | | Dissolved |
| RTV-90 | 55-90 | 30 | D | 11 | | | | Shrinks 5.9%, softened 14% |
| Epon 828 | 55-60 | 30 | D | 11 | | | | Broke apart |
| Paraplex P-43 | 55-60 | 30 | D | 11 | | | | Decomposed |
| Proseal 793 | 55-60 | 30 | D | 11 | | | | Dissolved |
| Fairprene 5156 | 55-60 | 30 | D | 11 | | | | Swollen; became brittle |

a — Definitions of ratings are given on page 4-14.

TABLE 4.2 (CONT)

COMPATIBILITY OF NONMETALS WITH 50/50 FUEL BLEND

| MATERIAL | TEMPERATURE DEGREES FAHRENHEIT | STATIC EXPOSURE LIQUID | | | STATIC EXPOSURE VAPOR | | | REMARKS |
|---|---|---|---|---|---|---|---|---|
| | | TIME IN DAYS | RATING[a] | REFERENCE | TIME IN DAYS | RATING[a] | REFERENCE | |
| **POTTING COMPOUNDS (CONT)** | | | | | | | | |
| Crystal M & CF | 55-80 | 90 | C | 11 | | | | Limited use |
| **ADHESIVES** | | | | | | | | |
| Armstrong A-5 | 55-80 | 90 | A | 10 | | | | Satisfactory |
| EC 847 | 55-80 | 30 | D | 11 | | | | Fell apart |
| HT 424 | 55-80 | 90 | A | 10 | | | | Satisfactory |
| **CERAMICS** | | | | | | | | |
| Temporell | 55-80 | 90 | A | 10 | | | | Satisfactory |
| Sauereisen P-1 | 55-80 | 90 | A | 10 | | | | Satisfactory |
| Sauereisen 31 | 55-80 | 90 | A | 10 | | | | Satisfactory |
| Sauereisen 47 | 75 | - | C | 4 | | | | Partly removed within 7 hours, limited service |
| Rockflux | 75 | - | A | 4 | | | | Satisfactory for 10.5 hours |
| **PAINTS** | | | | | | | | |
| Epoxy No. 1 | 55-80 | 30 | D | 11 | | | | Dissolved |
| Modified Epoxy No. 5 | 55-80 | 30 | D | 11 | | | | Edges swollen |

a — Definitions of ratings are given on page 4-14.

TABLE 4.2 (CONT)

COMPATIBILITY OF NONMETALS V 'H 50/50 FUEL BLEND

| MATERIAL | TEMPERATURE | | | | STATIC EXPOSURE | | | | |
| | DEGREES FAHRENHEIT | | | | LIQUID | | VAPOR | | |
| | | TIME IN DAYS | RATING[a] | REFERENCE | TIME IN DAYS | RATING[a] | REFERENCE | REMARKS |
|---|---|---|---|---|---|---|---|---|
| PAINTS (CONT) | | | | | | | | |
| Epoxy No. 7 | 55-60 | 30 | D | 11 | | | | Stripped off |
| Epoxy No. 9 | 55-60 | 30 | D | 11 | | | | Dissolved |
| Epoxy No. 8809 | 55-60 | 30 | D | 11 | | | | Peeled off |
| Alkyd No. 4 | 55-60 | 30 | D | 11 | | | | Stripped off |
| Polyurethane | 55-60 | 30 | D | 11 | | | | Stripped off |
| Acrylic Nitrocellulose | 55-60 | 30 | D | 11 | | | | Dissolved |
| Vinyl | 55-60 | 30 | D | 11 | | | | Blistered |
| Primer MIL-P-6880 | 55-60 | 30 | D | 11 | | | | Stripped off |
| Catalac | | | | | | | | |
| Primer and Finish | 160 | 7 | D | 4 | | | | Prime coat lifted immediately and other within 7 days |
| Improved | 160 | - | D | 4 | | | | Paint lifted within 1 minutes |
| Tygon K | 160 | - | D | 4 | | | | Paint blistered within 1 hour |
| Co-Polymer P-300 G | 160 | - | D | 4 | | | | Paint washed off within 3 minutes |
| CA 9747 Primer | 160 | - | D | 4 | | | | Blistered and dissolved within 10 minutes |
| Corrosile Clear 561 | 160 | - | D | 4 | | | | Blistered within 1 hour |

a — Definitions of ratings are given on page 4-14.

4.3   EFFECTS OF FUEL BLEND ON MATERIALS OF CONSTRUCTION

Table 4.3 is a list of construction materials showing the compatibility results of short exposure to fuel blend liquid spillage, fuel blend vapors, and watered fuel blend. Details of these tests are given in Reference 4. Coatings and/or surface treatments were applied to various materials to ascertain life expectancy. Of the organic coatings, Sauereisen 47 exhibits the best resistance. Rockflux, an inorganic concrete coating material having a viscous consistency when mixed with water, appears to be resistant to the 50/50 fuel blend. However, bare concrete is unaffected by the fuel blend.

TABLE 4.3

COMPATIBILITY OF CONSTRUCTION MATERIALS WITH
50/50 FUEL BLEND

| Material | Temperature (°F) | Exposure Time | Remarks |
|---|---|---|---|
| Birch Wood | 75 | 2 hr 30 min | Wood grain split |
| Concrete | | | |
|   Bare | 75 | 13 hr | No visual effect |
|   Coated with water glass | 75 | 1 hr 30 min | Water glass crystalized and powdered off |
|   Coated with water glass and floor enamel (Esco Brand 41138) | 75 | 1 hr 15 min | Paint blistered |
|   Coated with water glass and Chex-Wear floor enamel | 75 | 6 min | Paint blistered |
|   Coated with Rockflux | 75 | 10 hr 30 min | No visual effect |
| Mild Steel Coated with | | | |
|   Tygon K paint | 75 | 1 hr | Paint blistered |
|   Catalac improved paint | 75 | 1 hr 30 min | Grainy appearance; lifted when totally immersed |
|   Co-Polymer P-200G | 75 | 3 min | Paint was removed |
|   Sauereisen 47 (4 coatings) | 75 | 7 hr | First coating was removed in one hour; blistered but did not penetrate 4 coatings |
|   CA 9747 Primer paint | 75 | 10 min | Blistered and discolored |
|   Corrosite Clear 581 | 75 | 1 hr 15 min | Blistered |

## 4.4 EFFECTS OF METALS ON FUEL BLEND DECOMPOSITION

To determine the effects of materials on fuel decomposition, portions of unwelded, welded, brazed, and soldered metal specimens were sealed in Pyrex glass ampules with a small quantity of 50/50 fuel blend and placed in test for 14 days at 160°F. Blanks containing only fuel blend also were included as controls. After test, a weight loss of the fuel blend was indicative of decomposition. Details of this test are presented in Reference 2. The metals tested are shown in Table 4.4. Although the data obtained with this procedure is inconclusive, the specimens do not show signs of attack or discoloration and the fuel blend does not show signs of discoloration. Since the fuel samples subjected to spectral analyses are no worse than the control samples, no decomposition is attributable to the metals.

### TABLE 4.4

### METALS TESTED FOR DETERMINING
### 50/50 FUEL BLEND DECOMPOSITION

**Aluminum Alloys**

| | |
|---|---|
| 2014-T6 | manual welded and unwelded |
| 2014-T6 | machine welded |
| 5086 H-36 | manual welded and unwelded |
| 5456 H-321 | manual welded and unwelded |
| 6061-T6 | manual welded, brazed, and unwelded |

**Stainless Steels**

| | |
|---|---|
| 304L | annealed, manual welded and unwelded |
| 321 | annealed, manual welded and unwelded |
| 347 | annealed, manual welded, nicrobrazed, and unwelded |
| 410 | H & T, manual welded and unwelded |

**A-Nickel**    manual welded and unwelded

## 4.5   EFFECTS OF CONTAMINANTS ON FUEL BLEND

Filings of 2014 aluminum alloy and types 304, 316, and 347 stainless steels were exposed to 50/50 fuel blend at 160°F for 14 days to determine the potential effects of contaminants on the fuel blend picked up during systems manufacturing.  The metal filings were sealed in Pyrex glass ampules with fuel blend and, after test, the fuel blend weight loss indicated decomposition (References 2 and 4).  Although the data obtained from each test is inconclusive, no visual changes are apparent in either the fuel blend or the metal filings.  Also, no positive pressure was detected upon opening the test ampules.

Tests were made with 6061 aluminum alloy, type 347 stainless steel shavings, and lint exposed to the 50/50 fuel blend contained in glass flasks fitted with reflux condensers (Reference 2).  After one week at 160°F, no visual changes were detected in either the fuel or the metal, and spectral analyses of the fuel indicated no decomposition.  With lint, the analysis of the fuel blend is hampered by the absorption of the lint dye; however, observations during test indicate no decomposition.

# SECTION 5.0

# MATERIALS COMPATIBILITY, $N_2O_4$

# SECTION 5.0

# MATERIALS COMPATIBILITY, $N_2O_4$

## 5.1 EFFECTS OF $N_2O_4$ ON METALS

As a result of laboratory tests interpreted on the basis of practical experience, the individual metals are placed into the classifications described in Section 4.0, page 4-1 of this handbook.

Table 5.1 contains pertinent compatibility data, references, and ratings of several metals and metal alloys.

### 5.1.1 Aluminum Alloys

Aluminum alloys behave as stable materials because they are covered with a naturally occurring thin oxide film that is highly resistant and protective. These alloys have been known to withstand nitric acid above 82% by weight. Moist $N_2O_4$ produces 60% to 70% by weight nitric acid. The radical difference between aluminum alloys and stainless steel alloys is that the corrosion rate of stainless steel alloys in nitric acid decreases as the concentration is reduced, whereas the opposite is true of aluminum alloys.

Certain aluminum alloys exhibit higher corrosion rates when exposed to $N_2O_4$ containing varying water contents. The zinc-bearing 7075 aluminum alloy corrodes at a faster rate than the copper-bearing 2024 aluminum alloy. Under identical test conditions, both alloys corrode faster than 5052 and 3003 aluminum alloys; 3003 aluminum alloy exhibits the lowest corrosion rate (Reference 1). The evidence indicates that the purer the aluminum, the less the corrosion in $N_2O_4$ containing increased water content. The significance is not apparent until $N_2O_4$ contains greater than 0.3% water.

The alloys tested cover a variety of casting and wrought alloys that are characterized by good strength, weldability, formability, and corrosion resistance.

There was no major difference in mechanical properties as a result of the testing in the presence of $N_2O_4$ having a water content of 0.2% maximum and up to a temperature of 165°F. There was no effect on the alloy tested when in contact with Teflon (Reference 16). The criterion for resistance of the alloys is the water content of the $N_2O_4$.

The application of a heavier oxide film by electrolytic means or chemical conversion does not result in a major difference in corrosion regardless of the water content of the $N_2O_4$.

5.1.2  Stainless Steels

The stainless steels mentioned in Table 5.1 are a cross-section of alloys that are durable, heat- and corrosion-resistant, and non-contaminating. They contain at least 12% chromium, often 7% or more nickel, and additives such as molybdenum, columbium, and titanium. Included are the hardenable heat-resistant alloys which lack nickel. All these alloys are resistant to $N_2O_4$ oxidizing conditions, including the presence of nitric acid.

Maximum corrosion resistance of the stainless steels can be attained by proper fabrication techniques. The effect of welding, brazing, and improper heat treatments on the corrosion resistance of stainless steels is well known. Included in Table 5.1 are specimens prepared by means of acceptable fabrication procedures.

A limited number of $N_2O_4$ metal corrosion tests conducted by the Nitrogen Division of Allied Chemical Corporation (Reference 16) indicates that the presence of Teflon can increase the corrosion rate of type 304L SS. However, corrosion rates of 304L SS with and without Teflon are less than 1 MPY with specification-grade $N_2O_4$ at 165°F for 70 days and with $N_2O_4$ containing as much as 2% water at 115°F for 109 days.

Under the test conditions stated in Table 5.1, regardless of the source of information, there is no major difference in the mechanical properties of stainless steel. This includes welded, nicrobrazed, tin-soldered, and silver-brazed joints. Tin solder and silver brazing are readily attacked by dilute nitric acid; therefore, this fabrication procedure must be used with discretion because severe corrosion could occur with increased water content of the $N_2O_4$.

5.1.3  Ferrous Alloys

The ferrous alloys are not known to have high resistance to oxidizing conditions and their use is a matter of economics. This is specifically true when nitric acid is the oxidizer; however, at high concentrations of nitric acid, the corrosion rate reaches a low value. The ferrous alloys are unaffected by $N_2O_4$ having 0.4% water maximum up to 165°F. A limited number of tests conducted by the Nitrogen Division of Allied Chemical Corporation (Reference 16) indicates that the presence of Teflon can increase the corrosion rate of carbon steel. However, corrosion rates of ASTM-A285 grade C are less than 1 MPY when exposed to specification-grade $N_2O_4$ at 115°F for 109 days and 165°F for 70 days.

5.1.4  Nickel Alloys

In general, oxidizing conditions promote corrosion of nickel alloys. Nickel can protect itself against certain forms of attack by developing a passive oxide film; thus, oxidizing conditions do not always accelerate the corrosion of nickel. While these alloys show good resistance

to dry $N_2O_4$, caution is advised in their use with moist $N_2O_4$. An exception to this is Inconel which has good corrosion resistance to oxidizing conditions.

### 5.1.5 Titanium Alloys

Commercially pure titanium is outstanding among structural materials in its resistance at ordinary temperatures to oxidizing conditions. Titanium, when passivated, is the noble metal in a galvanic couple with all structural alloys except Monel and stainless steels. The titanium alloys are generally less resistant to corrosion than commercially pure titanium. Care has been exercised in exploring new combinations of titanium alloys and corrosive mediums. This is due to its pyrophoric properties in RFNA and its impact sensitivity with liquid oxygen and fluorine. However, it is only in the case of liquid oxygen that the reaction may propagate and completely consume the titanium. In most cases, even though ignition occurs, the damage is not significantly greater than that resulting from the impact alone. A smooth, surgically clean titanium surface minimizes the reaction (Reference 22). The data in Table 5.1 shows that the titanium alloys are virtually unaffected by $N_2O_4$ and moist $N_2O_4$ up to 25% by weight. No ill effects occur when coupled to 2014-T6 aluminum alloy in $N_2O_4$. (See Propellant Handling, Section 6.0, for additional data substantiating the use of titanium with $N_2O_4$.) All testing to date indicates that titanium alloys are satisfactory for use with $N_2O_4$.

### 5.1.6 Magnesium Alloys

Magnesium alloys corrode in $N_2O_4$ and corrosion products form on the surface of the metals.

### 5.1.7 Copper Alloys

Berylco 25 exhibits a corrosion rate of less than 1 MPY; however, because corrosion products form on the surface of this alloy and are easily removed, a "C" rating is assigned.

### 5.1.8 Cobalt Alloys

Haynes Stellites No. 6K and 25 exhibit good corrosion resistance with $N_2O_4$.

### 5.1.9 Platings

Gold-plated Berylco 25 exhibits a corrosion rate less than 1 MPY; however, because corrosion products form on the surface and are removed easily, a "C" rating is assigned. Non-porous chromium, nickel plating, and electroless nickel are satisfactory for $N_2O_4$ service.

5.1.10  Conversion Coatings

There is evidence to show that sulfuric acid anodize, Hardas ano    , and iridite aluminum conversion coatings are resistant to $N_2O_4$ exposure.

5.1.11  Miscellaneous Alloys

Silver solder, as reported in Reference 10, becomes badly pitted    $N_2O_4$ after one month and exhibits a high corrosion rate.  Tantalum exhibits good corrosion r    tance to $N_2O_4$.

## TABLE 5.1

### COMPATIBILITY OF METALS WITH $N_2O_4$

| MATERIAL | TEMPERATURE DEGREE FAHRENHEIT | LIQUID TIME IN DAYS | LIQUID RATING[a] | LIQUID REFERENCE | VAPOR TIME IN DAYS | VAPOR RATING[a] | VAPOR REFERENCE | INTERFACE TIME IN DAYS | INTERFACE RATING[a] | INTERFACE REFERENCE | REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **ALUMINUM ALLOYS** | | | | | | | | | | | |
| 1100-0 | 55-60 | 90 | A | 15,11 19 | | | | | | | |
| | 100 | 7 | A | 18 | | | | | | | 0.1 to 0.3% $H_2O$ |
| 2014-T6 Sheet | | | | | | | | | | | |
| Unwelded | 55-60 | 90 | A | 15,11 | 90 | A | 15,11 | 90 | A | 15 | |
| Welded | 55-60 | 90 | A | 15,11 | 90 | A | 15,11 | | | | |
| | 63-67 | 14 | A | 4 | | | | | | | |
| Spotwelded | 55-60 | 180 | D | 15,11 | 180 | D | 15,11 | | | | "D" rating because of cracks in spotweld |
| 2014-T6 Extrusion | | | | | | | | | | | |
| Unwelded | 55-60 | 90 | A | 15 | | | | | | | |
| Stressed to 50,000 psi | 55-60 | 90 | A | 15 | | | | | | | 0.2% $H_2O$ |
| Welded | 55-60 | 90 | A | 15 | 90 | A | 15 | | | | 0.6% $H_2O$ added |
| Stressed to 30,000 psi | 55-60 | 90 | A | 15 | | | | | | | |
| | 55-60 | 30 | A | 15 | | | | | | | 0.2% $H_2O$ |
| Stressed to 50% and 80% Yield | 55-60 | | | | | | | 30 | A | 15 | |
| 2024-0 | 55-65 | 63 | A[b] | 19 | 63 | A[b] | 19 | 63 | A | 19 | |
| | 100 | 7 | A | 1,19 | | | | | | | "B" rating at 0.2%, "C" rating above 0.7% $H_2O$ |
| | 140 | 11 | A | 19 | | | | | | | |
| | 150 | 7 | B | 14 | 7 | A | 14 | | | | 0.6% $H_2O$ |
| | 150 | 7 | A | 14 | 7 | A | 14 | | | | |

a — Definitions of ratings are given on page 4-1.
b — Predicted rating from interface data.

## TABLE 5.1 (CONT)

## COMPATIBILITY OF METALS WITH $N_2O_4$

| MATERIAL | TEMPERATURE DEGREES FAHRENHEIT | STATIC EXPOSURE LIQUID | | | VAPOR | | | INTERFACE | | | REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | TIME IN DAYS | RATING[a] | REFERENCE | TIME IN DAYS | RATING[a] | REFERENCE | TIME IN DAYS | RATING[a] | REFERENCE | |
| **ALUMINUM ALLOYS (CONT)** | | | | | | | | | | | |
| 2219-T81 Welded and Unwelded | 55-60 | 90 | A | 15 | | | | | | | No effect, up to 0.3% $H_2O$ |
| 3003-H14 | 100 | 7 | A | 1,19 | | | | | | | Up to 0.4% $H_2O$ |
| | 150 | 7 | A | 14 | 7 | A | 14 | | | | Up to 0.6% $H_2O$ |
| 5052-0 | 100 | 7 | A | 1,19 | | | | | | | "B" rating at 0.3% to 1.0% $H_2O$ |
| | 140 | 29 | B | 19 | | | | | | | |
| 5086-H34 Unwelded | 15 | 56 | A | 16 | | | | | | | Up to 0.4% $H_2O$ |
| | 70 | 27 | A | 16 | | | | | | | Up to 0.6% $H_2O$ |
| | 70 | 27 | B | 16 | | | | | | | 1.6% $H_2O$ |
| | 70 | 27 | C | 16 | | | | | | | 3.2% $H_2O$ |
| | 115 | 109 | A | 16 | | | | | | | Up to 0.5% $H_2O$ |
| | 115 | 109 | B | 16 | | | | | | | 1.0% $H_2O$ |
| | 115 | 109 | C | 16 | | | | | | | 2.0 to 3.0% $H_2O$ |
| | 120 | 27 | A | 16 | | | | | | | Up to 0.4% $H_2O$ |
| | 120 | 27 | B | 16 | | | | | | | 0.8% $H_2O$ |
| | 120 | 27 | C | 16 | | | | | | | 1.6% $H_2O$ |
| | 120 | 27 | D | 16 | | | | | | | 3.2% $H_2O$ |
| | 165 | 70 | A | 16 | | | | | | | |
| | 165 | 70 | B | 16 | | | | | | | 0.5% $H_2O$ |
| | 165 | 70 | C | 16 | | | | | | | 1.0% $H_2O$ |
| | 165 | 70 | D | 16 | | | | | | | 2.0 to 3.0% $H_2O$ |
| Welded | 15-165 | 27 | A | 16 | | | | | | | $<$0.4% $H_2O$ |
| | 15-165 | 27 | B | 16 | | | | | | | 0.4 to 3.2% $H_2O$ |

a — Definitions of ratings are given on page 4-1.

## TABLE 5.1 (CONT)

## COMPATIBILITY OF METALS WITH $N_2O_4$

| MATERIAL | TEMPERATURE DEGREES FAHRENHEIT | LIQUID | | | VAPOR | | | INTERFACE | | | REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | TIME IN DAYS | RATING | REFERENCE | TIME IN DAYS | RATING | REFERENCE | TIME IN DAYS | RATING | REFERENCE | |
| **ALUMINUM ALLOYS (CONT)** | | | | | | | | | | | |
| **5086-H36** | | | | | | | | | | | |
| Unwelded | 63-67 | 90 | A$^b$ | 4 | 90 | A$^b$ | 4 | 90 | A | 4 | |
| Welded | 63-67 | 14 | A | 4 | | | | | | | |
| **5254-F** | 63-67 | 90 | A$^b$ | 4 | 90 | A$^b$ | 4 | 90 | A | 4 | |
| **5456-H24** Welded and Unwelded | 55-60 | 90 | A | 15 | | | | | | | |
| **5456-H321** | | | | | | | | | | | |
| Unwelded | 55-60 | 90 | A | 15 | | | | | | | 0.2% $H_2O$ |
| | 63-67 | 14 | A | 4 | | | | | | | |
| Stressed to 30,000 psi | 55-60 | 30 | A | 15 | | | | | | | 0.2% $H_2O$ |
| Welded | 55-60 | 30 | A | 15 | 30 | A | 15 | | | | 0.6% $H_2O$ |
| Stressed to 20,000 psi | 55-60 | 30 | A | 15 | | | | | | | 0.2% $H_2O$ |
| **6061-T6** | 55-60 | 90 | A | 10 | 90 | A$^b$ | 4 | 90 | A | 4 | |
| Unwelded | 63-67 | 90 | A$^b$ | 4 | 90 | A$^b$ | 4 | 90 | A | 4 | |
| | 130 | 30 | A | 19 | | | | | | | 0.5% $H_2O$ |
| | 100 | 7 | A | 18 | | | | | | | 0.3% $H_2O$ |
| | 150 | 7 | A | 14 | 7 | A | 14 | | | | Up to 0.6% $H_2O$ |
| Welded | 55-60 | 90 | A | 15 | | | | | | | |
| | 63-67 | 14 | A | 4 | | | | | | | |
| **6066** | 63-67 | 90 | A$^b$ | 4 | 90 | A$^b$ | 4 | 90 | A | 4 | |
| **7075-T6** | 55-60 | 90 | A | 15 | | | | | | | 0.6% $H_2O$ |

a — Definitions of ratings are given on page 4-1.
b — Predicted rating from interface data.

## TABLE 5.1  (CONT)

## COMPATIBILITY OF METALS WITH $N_2O_4$

| MATERIAL | TEMPERATURE DEGREES FAHRENHEIT | STATIC EXPOSURE — LIQUID | | | STATIC EXPOSURE — VAPOR | | | STATIC EXPOSURE — INTERFACE | | | REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | TIME IN DAYS | RATING[a] | REFERENCE | TIME IN DAYS | RATING[a] | REFERENCE | TIME IN DAYS | RATING[a] | REFERENCE | |
| **ALUMINUM ALLOYS (CONT)** | | | | | | | | | | | |
| 7075-0 | 100 | 7 | A | 1,18 | | | | | | | "B" rating at 0.2% $H_2O$; "C" rating above 0.5% $H_2O$ |
| | 150 | 7 | A | 14 | 7 | A | 14 | | | | |
| | 150 | 7 | B | 14 | 7 | B | 14 | | | | 0.3% $H_2O$ |
| | 55-65 | 30 | A[b] | 19 | 30 | A[b] | 19 | 30 | A | 19 | |
| 356-T6 | 55-60 | 90 | A | 15 | | | | | | | 0.2% $H_2O$ |
| | 55-65 | 30 | A[b] | 19 | 30 | A[b] | 19 | 30 | A | 19 | |
| Tens 50 | 63-67 | 90 | A[b] | 4 | 90 | A[b] | 4 | 90 | A | 4 | |
| **STAINLESS STEELS** | | | | | | | | | | | |
| 302 | 100 | 7 | A | 19 | | | | | | | |
| 303 | 63-67 | 90 | A[b] | 4 | 90 | A[b] | 4 | 90 | A | 4 | |
| | 100 | 7 | A | 19 | | | | | | | |
| 304 | 55-65 | 63 | A[b] | 19 | 63 | A[b] | 19 | 63 | A | 19 | |
| **304L** | | | | | | | | | | | |
|   Unwelded | 55-60 | 90 | A | 15 | | | | | | | 0.2% $H_2O$ |
| | 63-67 | 14 | A | 4 | | | | | | | |
| | 15-165 | 27 | A | 16 | | | | | | | Up to 3.2% $H_2O$ Incl |
|   Welded | 63-67 | 14 | A | 4 | | | | | | | |
| 316 | 63-67 | 90 | A[b] | 4 | 90 | A[b] | 4 | 90 | A | 4 | |
| | 63-67 | 90 | A[b] | 4 | 90 | A[b] | 4 | 90 | A | 4 | |

a — Definitions of ratings are given on page 4-1.
b — Predicted rating from interface data.

## TABLE 5.1 (CONT)

## COMPATIBILITY OF METALS WITH $N_2O_4$

| MATERIAL | TEMPERATURE DEGREES FAHRENHEIT | STATIC EXPOSURE LIQUID | | | VAPOR | | | INTERFACE | | | REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | TIME IN DAYS | RATING[a] | REFERENCE | TIME IN DAYS | RATING[a] | REFERENCE | TIME IN DAYS | RATING[a] | REFERENCE | |
| **STAINLESS STEELS (CONT)** | | | | | | | | | | | |
| 321 | | | | | | | | | | | |
| Unwelded | 55-80 | 180 | A | 19 | 180 | A | 15 | 180 | A | 15 | |
| Welded | 55-80 | 180 | A | 15 | | | | | | | Up to 2.0% $H_2O$ |
| | 63-67 | 14 | A | 4 | | | | | | | |
| 347 | | | | | | | | | | | |
| Unwelded | 55-80 | 180 | A | 15 | | | | | | | |
| | 63-97 | 90 | A[b] | 4 | 90 | A[b] | 4 | 90 | A | 4 | |
| | 130 | 30 | A | 19 | | | | | | | |
| | 100 | 15 | A | 15 | | | | | | | 10% $H_2O$ |
| Welded | 55-80 | 180 | A | 15 | | | | | | | |
| | 63-97 | 14 | A | 4 | | | | | | | |
| 17-4 PH Cond. A | 63-97 | 90 | A[b] | 4 | 90 | A[b] | 4 | 90 | A | 4 | |
| 17-4 PH (H 1100) | 100 | 10 | A | 14 | | | | | | | Up to 0.2% $H_2O$ |
| 17-7 PH | 54-95 | 30 | A[b] | 19 | 30 | A[b] | 18 | 30 | A | 19 | |
| 17-7 PH TH 950 | 100 | 14 | A | 14 | | | | | | | Up to 2.0% $H_2O$ |
| 17-7 PH RH 950 | 100 | 14 | A | 15 | | | | | | | Up to 0.2% $H_2O$ |
| PH 15-7 Mo Cond. A | 63-97 | 90 | A[b] | 4 | 90 | A[b] | 4 | 90 | A | 4 | |
| | 13-103 | 37 | A | 10 | | | | | | | Up to 1.2% $H_2O$ |
| AM 366 Cond. H | 63-97 | 90 | A[b] | 4 | 90 | A[b] | 4 | 60 | A | 4 | |

a — Definitions of ratings are given on page 4-1.
b — Predicted rating from interface data.

TABLE 5.1 (CONT)

## COMPATIBILITY OF METALS WITH $N_2O_4$

| MATERIAL | TEMPERATURE | | | LIQUID | | | VAPOR | | | INTERFACE | REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Degrees Fahrenheit | Time in Days | Rating[a] | Reference | Time in Days | Rating[a] | Reference | Time in Days | Rating[a] | Reference | |
| **STAINLESS STEELS (CONT)** | | | | | | | | | | | |
| AM 350 Ann. | 100 | 10 | A | 18 | | | | | | | 10% $H_2O$ |
| A 286 Ann. | 55-60 | 90 | A | 15 | | | | | | | |
| | 100 | 7 | A | 14 | | | | | | | Up to 0.5% $H_2O$ |
| 410 H & T | 63-67 | 90 | A[b] | 4 | 90 | A[b] | 4 | 90 | A | 4 | |
| Welded | 63-67 | 14 | A | 4 | | | | | | | |
| 410 (Rc 41) | 100 | 7 | A | 14 | | | | | | | Up to 1% $H_2O$ |
| | 150 | 7 | A | 14 | | | | | | | |
| 416 | 55-65 | 30 | A[b] | 19 | 30 | A[b] | 19 | 30 | A | 19 | |
| 440 C | 63-67 | 90 | A[b] | 4 | 90 | A[b] | 4 | 90 | A | 4 | |
| Ann. | 100 | 7 | A | 14 | | | | | | | Up to 0.6% $H_2O$ |
| **FERROUS ALLOYS** | | | | | | | | | | | |
| ASTM A-285 (Grade C) | 15 | 27 | A | 16 | | | | | | | Up to 3.2% $H_2O$ Incl |
| | 70 | 27 | A | 16 | | | | | | | Up to 0.8% $H_2O$ Incl |
| | 70 | 27 | B | 16 | | | | | | | 1.6 to 3.2% $H_2O$ |
| | 120 | 27 | A | 16 | | | | | | | Up to 0.4% $H_2O$ Incl |
| | 120 | 27 | B | 16 | | | | | | | 0.8% $H_2O$ |
| | 120 | 27 | C | 16 | | | | | | | >0.8% $H_2O$ to 3.2% Incl |
| | 165 | 27 | A | 16 | | | | | | | Up to 0.4% $H_2O$ Incl |
| | 165 | 27 | B | 16 | | | | | | | 0.8% $H_2O$ |
| | 165 | 27 | C | 16 | | | | | | | >0.8% $H_2O$ to 3.2% Incl |

a — Definitions of ratings are given on page 4-1.
b — Predicted rating from interface data.

## TABLE 5.1 (CONT)

## COMPATIBILITY OF METALS WITH $N_2O_4$

| MATERIAL | TEMPERATURE DEGREES FAHRENHEIT | STATIC EXPOSURE | | | | | | | | | REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | LIQUID | | | VAPOR | | | INTERFACE | | | |
| | | TIME IN DAYS | RATING[a] | REFERENCE | TIME IN DAYS | RATING[a] | REFERENCE | TIME IN DAYS | RATING[a] | REFERENCE | |
| **FERROUS ALLOYS (CONT)** | | | | | | | | | | | |
| 1030 | 35-90 | 90 | A | 15 | | | | | | | 0.2% H₂O |
| | 135 | 30 | A | 19 | | | | | | | |
| 8630 | 140 | 29 | A | 19 | | | | | | | |
| **NICKEL ALLOYS** | | | | | | | | | | | |
| Inconel | 35-65 | 33 | A[b] | 19 | 33 | A[b] | 19 | 33 | A | 19 | |
| Monel[c] | 55-65 | 63 | A[b] | 19 | 63 | A[b] | 19 | 63 | A | 19 | |
| "A" Nickel[c] Welded and Unwelded | 63-67 | 14 | A | 4 | | | | | | | |
| Ni Span C | 55-60 | 30 | A | 19 | | | | | | | 0.2% H₂O |
| Nilvar | 55-60 | 30 | A | 19 | | | | | | | |
| **TITANIUM ALLOY** | | | | | | | | | | | |
| B120 VCA | 35-80 | 90 | A | 15 | | | | | | | |
| C120 AV | 35-60 | 90 | A | 19 | | | | | | | |
| | 70-105 | 27 | A | 19 | | | | | | | Up to 2.2% H₂O |
| T5A | 70-105 | 17 | A | 19 | | | | | | | Up to 1.9% H₂O |
| Ti 65A | 100 | 14 | A | 19 | | | | | | | Up to 20% H₂O |
| RC 130 AM | 100-150 | | | | | | | 14 | A | 19 | 2% H₂O, discoloration in vapor |
| A 110 AT | 35-85 | 7 | A[b] | 19 | 7 | A[b] | 19 | 7 | A | 19 | |

a -- Definitions of ratings are given on page 4-1.
b -- Predicted rating from interface data.
c -- These alloys are highly susceptible to corrosion in nitric acid.

TABLE 5.1 (CONT)

COMPATIBILITY OF METALS WITH $N_2O_4$

| MATERIAL | TEMPERATURE DEGREES FAHRENHEIT | STATIC EXPOSURE | | | | | | | | | REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | LIQUID | | | VAPOR | | | INTERFACE | | | |
| | | TIME IN DAYS | RATING[a] | REFERENCE | TIME IN DAYS | RATING[a] | REFERENCE | TIME IN DAYS | RATING[a] | REFERENCE | |
| MAGNESIUM ALLOYS | | | | | | | | | | | |
| HM 21A T8[c] | 55-60 | 30 | A | 18 | | | | | | | 3.0% $H_2O$ |
| AZ 31C[c] | 55-65 | | | | | | | 68 | D | 19 | "D" rating because of slight corrosion products |
| AM 100A[c] | 55-65 | | | | | | | 68 | D | 19 | "D" rating because of slight corrosion products |
| COPPER ALLOYS | | | | | | | | | | | |
| Beryloo 25[c] | 63-87 | | | | | | | 90 | C | 4 | Corrosion products |
| COBALT ALLOYS | | | | | | | | | | | |
| Haynes Stellite | | | | | | | | | | | |
| 6K | 55-65 | 68 | A[b] | 19 | 67 | A[b] | 19 | 68 | A | 19 | |
| 25 | 63-87 | 90 | A[b] | 4 | 90 | A[b] | 4 | 90 | A | 4 | |
| PLATINGS | | | | | | | | | | | |
| Cadmium | 55-60 | - | D | 18 | | | | | | | |
| Chromium (non-porous) | 55-60 | - | A | 18 | | | | | | | |
| Copper[c] | 55-60 | - | C | 18 | | | | | | | |
| Gold on Beryloo 25 | 63-87 | | | | | | | 90 | C | 4 | Plating porous, corrosion products |

a — Definitions of ratings are given on page 4-1.
b — Predicted rating from interface data.
c — These alloys are highly susceptible to corrosion in nitric acid.

## TABLE 5.1 (CONT)

## COMPATIBILITY OF METALS WITH $N_2O_4$

| MATERIAL | TEMPERATURE DEGREES FAHRENHEIT | STATIC EXPOSURE LIQUID | | | VAPOR | | | INTERFACE | | | REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | TIME IN DAYS | RATING [a] | REFERENCE | TIME IN DAYS | RATING [a] | REFERENCE | TIME IN DAYS | RATING [a] | REFERENCE | |
| PLATINGS (CONT) | | | | | | | | | | | |
| Nickel | | | | | | | | | | | |
| Electrolytic (non-porous) | 55-60 | - | A | 15 | | | | | | | |
| Electroless | 100 | T | A | 15 | | | | | | | Up to 0.3% $H_2O$ |
| Silver | 55-60 | - | D | 15 | | | | | | | |
| Zinc | 55-60 | - | D | 15 | | | | | | | |
| COATINGS ON ALUMINUM ALLOYS | | | | | | | | | | | |
| Iridite | | | | | | | | | | | |
| 2014-T6 | | | | | | | | | | | |
| Welded | 55-60 | 30 | A | 10,11 | | | | | | | 0.369% $H_2O$ |
| | 55-60 | | | | 90 | A | 10,11 | | | | |
| Unwelded | 55-60 | | | | 30 | A | 10 | | | | 2.12% $H_2O$ |
| 2219-T81 Welded | 55-60 | 30 | A | 10 | | | | | | | 1.39% $H_2O$ |
| 5456-H34 Welded | 55-60 | 90 | A | 15 | | | | | | | |
| 6061-T6 Welded | 55-60 | 90 | A | 15 | | | | | | | |
| Sulfuric Acid Anodize | | | | | | | | | | | The coatings do not improve resistance to oxidizer; data too scattered for conclusive evidence |
| 7075-0 | 100 | T | B | 15 | | | | | | | |
| A 356 | 100 | T | B | 15 | | | | | | | |
| | 100 | T | B | 15 | | | | | | | |

a — Definitions of ratings are given on page 4-1.

TABLE 5.1 (CONT)

COMPATIBILITY OF METALS WITH $N_2O_4$

| MATERIAL | TEMPERATURE DEGREES FAHRENHEIT | STATIC EXPOSURE | | | | | | | | | REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | LIQUID | | | VAPOR | | | INTERFACE | | | |
| | | TIME IN DAYS | RATING[a] | REFERENCE | TIME IN DAYS | RATING[a] | REFERENCE | TIME IN DAYS | RATING[a] | REFERENCE | |
| COATINGS ON ALUMINUM ALLOYS (CONT) | | | | | | | | | | | |
| 2014-T6 Al Hardas Anodize | 63-67 | | | | 30 | A | 4 | | | | |
| 2014-T6 Al Hard Coat (Sanfurize) | 55-60 | 30 | A | 15 | | | | | | | |
| 2014 | 100 | 7 | B | 18 | | | | | | | |
| A 356 | 100 | 7 | A | 18 | | | | | | | |
| 7075 | 100 | 7 | B | 18 | | | | | | | |
| MISCELLANEOUS | | | | | | | | | | | |
| Microseal 100-1 on AM 100A Magnesium | 63-67 | | | | 100 | D | 4 | | | | Coating porous, metal attacked |
| Microseal 100-1 CG on AZ 31C Magnesium | 63-67 | | | | 75 | D | 4 | | | | Coating porous, metal attacked |
| Microseal 100-1 on 2014-T6 Al | 63-67 | | | | 100 | A | 4 | | | | Coating porous, see data above for coating on Magnesium |
| Silver Solder[c] | 55-60 | 30 | D | 10 | | | | | | | Pitting |
| Tantalum | 55-65 | 30 | $A^b$ | 19 | 30 | $A^b$ | 19 | 30 | A | 19 | |

a — Definitions of ratings are given on page 4-1.
b — Predicted rating from interface data.
c — These alloys are highly susceptible to corrosion in nitric acid.

TABLE 5.1  (CONT)

COMPATIBILITY OF METALS WITH $N_2O_4$

| MATERIAL | TEMPERATURE DEGREES FAHRENHEIT | STATIC EXPOSURE | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | LIQUID | | | VAPOR | | | INTERFACE | | | REMARKS |
| | | TIME IN DAYS | RATING[a] | REFERENCE | TIME IN DAYS | RATING[a] | REFERENCE | TIME IN DAYS | RATING[a] | REFERENCE | |
| **BRAZING AND SOLDERING** | | | | | | | | | | | |
| 6061-T6 Al brazed with 718 filler | 63-67 | 14 | A | 4 | | | | | | | |
| 303 SS soldered with pure Tin | 63-67 | 14 | A | 6 | | | | | | | |
| 347 SS silver brazed with Easy Flo per QQS-561 Class 4 | 63-67 | 14 | A | 4 | | | | | | | |
| 347 SS micro-brazed AMS 4775 | 63-67 | 14 | A | 4 | | | | | | | |
| **METAL COUPLES** | | | | | | | | | | | |
| 2014-T6 Al coupled to Teflon | 63-67 | | | | | | | 30 | A | 4 | Teflon in tape or bar form had no effects |
| 2014-T6 Al bolted to 6Al-4V Titanium | 55-60 | 90 | A | 15 | | | | | | | 0.7% $H_2O$ |
| 2014-T6 Al bolted to 321 SS | 55-60 | 90 | A | 15 | | | | | | | 0.7% $H_2O$ |
| 2014-T6 Al welded to 6061-T6 Al | 63-67 | 14 | A | 4 | | | | | | | |

a — Definitions of ratings are given on page 4-1.

## TABLE 5.1 (CONT)

## COMPATIBILITY OF METALS WITH $N_2O_4$

| MATERIAL | TEMPERATURE DEGREES FAHRENHEIT | LIQUID TIME IN DAYS | RATING[a] | REFERENCE | VAPOR TIME IN DAYS | RATING[a] | REFERENCE | INTERFACE TIME IN DAYS | RATING[a] | REFERENCE | REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **METAL COUPLES (CONT)** | | | | | | | | | | | |
| 304 SS/ Teflon/321 SS bolted | 55-90 | 30 | A | 15 | | | | | | | 0.7% $H_2O$ |
| 304L coupled with Teflon | 15 | 55 | A | 16 | | | | | | | Up to 1.0% $H_2O$ Incl |
| | 115 | 109 | A | 16 | | | | | | | Up to 2.0% $H_2O$ Incl |
| | 165 | 70 | A | 16 | | | | | | | |
| | 165 | 70 | B | 16 | | | | | | | 0.5 to 3.0% $H_2O$ Incl |
| | 63-87 | | | | | | | 30 | A | 4 | Tape or bar Teflon had no effect |
| **ASTM A-285 (Grade C)** | | | | | | | | | | | |
| In presence of Teflon | 15 | 55 | A | 16 | | | | | | | Up to 1.0% $H_2O$ Incl |
| | 115 | 109 | A | 16 | | | | | | | |
| | 115 | 109 | B | 16 | | | | | | | >0.1% to 2.0% $H_2O$ Incl |
| | 115 | 109 | C | 16 | | | | | | | 3.0% $H_2O$ |
| | 165 | 70 | A | 16 | | | | | | | |
| | 165 | 70 | B | 16 | | | | | | | 0.5 to 1.0% $H_2O$ Incl |
| | 165 | 70 | C | 16 | | | | | | | 2 to 3% $H_2O$ Incl |

a — Definitions of ratings are given on page 4-1.

## 5.2   EFFECTS OF $N_2O_4$ ON NONMETALS

Table 5.2 contains compatibility data, references, and the ratings of several nonmetals exposed to $N_2O_4$. The ratings are identical with those described in Section 4.0, page 4-13, on the 50/50 fuel blend materials compatibility.

An intimate knowledge of the behavior of plastics, rubbers, and elastomers under the conditions of their intended use is a prerequisite for engineering design. Being chiefly organic, the nonmetals are generally sensitive to $N_2O_4$ and their mechanical properties in this environment are more susceptible to changes in a short range of temperature.

The chemical environment can act on these materials in several ways. The propellant can dissolve, attack, and decompose the material causing degradation, or it can completely destroy the material. Moreover, the propellant can extract some components, thereby altering physical properties, or it can be absorbed by the material and thus affect the strength. In addition, the chemical environment can affect the dimensional stability and finish appearance without seriously affecting the mechanical properties. The nonmetals tested embrace a wide variety of chemical and physical structures and, as such, geometrical factors, methods of fabrication, and similar variables can greatly influence the behavior of a part fabricated from any of the nonmetals shown in Table 5.2.

For example, many of these nonmetals can be used as gaskets or seals where a definite compression set limitation and, probably volume change limitation, is required for sealing. The gasket or seal can be enclosed between two metal surfaces with only a small portion exposed to the medium. The swelling characteristics of this type exposure differ in magnitude and importance when compared with the swelling obtained from complete immersion in the medium where volume change is magnified. Tensile properties play a small role in the application of the material for a gasket; when used as an O-ring, tensile properties are important. Therefore, the application of any of the nonmetals must be weighed in terms of the physical properties desired.

### 5.2.1   Plastics

The Teflon and Teflon products exhibit the best resistance to $N_2O_4$; however, $N_2O_4$ permeates and is absorbed by Teflon. The important considerations are the retention of properties after outgassing the $N_2O_4$. Teflon swells approximately 5% before outgassing and returns to its original volume after outgassing.

The polyethylenes absorb $N_2O_4$ and increase in brittleness with time. Certain polyethylenes show good resistance to $N_2O_4$ for periods up to 30 days.

### 5.2.2 Elastomers

The fluororubbers swell considerably in $N_2O_4$ and have a negative volume change after outgassing.

Phenolic resin-cured butyls and fluorosilicone rubbers show resistance to $N_2O_4$. Even these are good for only short-term service.

### 5.2.3 Lubricants and Sealants

Reddy Lubes 100 and 200 and water glass/graphite mixture are satisfactory thread sealants. All the lubricants either react or wash off in $N_2O_4$; however, for assembly purposes, Nordcoseal greases can be used satisfactorily. Dry lubricants Molykote Z, Drilube 703, and Electrofilm 66 C are satisfactory for use with $N_2O_4$.

### 5.2.4 Potting Compounds and Ceramics

Only Sauereisen P-1, a ceramic, exhibits satisfactory resistance to $N_2O_4$. There are no potting compounds satisfactory for service with $N_2O_4$.

### 5.2.5 Adhesives

Testing to date indicates that there are no adhesives satisfactory for service with $N_2O_4$.

### 5.2.6 Paints

Testing to date indicates that there are no paints satisfactory for service with $N_2O_4$.

### 5.2.7 Miscellaneous

Graphitar 2 and 50 are satisfactory for service with $N_2O_4$.

TABLE 5.2

COMPATIBILITY OF NONMETALS WITH $N_2O_4$

| MATERIAL | TEMPERATURE DEGREES FAHRENHEIT | TIME IN DAYS | RATING[a] | STATIC EXPOSURE LIQUID REFERENCE | TIME IN DAYS | RATING[a] | VAPOR REFERENCE | REMARKS |
|---|---|---|---|---|---|---|---|---|
| PLASTICS | | | | | | | | |
| Polytetrafluoroethylene | | | | | | | | |
| Teflon (TFE) | 55-60 | 30 | B | 11 | | | | 1% to 3% $H_2O$ |
| | 63-67 | 30 | A | 4 | | | | |
| | 70-80 | 100 | B | 1,11 | | | | Softened 20% |
| Teflon filled with graphite | 55-60 | 90 | A | 15 | | | | |
| Teflon filled with molydisulfide | 55-60 | 90 | A | 15 | | | | |
| Teflon filled with asbestos | 55-60 | 90 | A | 15 | | | | |
| Armalon 7700 impregnated with Teflon fibers | 55-60 | 90 | A | 15 | | | | |
| Armalon 7700B impregnated with Teflon fibers | 55-60 | 90 | A | 15 | | | | |
| Fluorobestos filled with asbestos | 55-60 | 30 | B | 11 | | | | Increased hardness 39% |
| TFE-felt 7550 | 55-60 | 30 | D | 11 | | | | Sample coming apart |

a — Definitions of ratings are given on page 4-14.

TABLE 5.2 (CONT)

## COMPATIBILITY OF NONMETALS WITH $N_2O_4$

| MATERIAL | TEMPERATURE DEGREES FAHRENHEIT | STATIC EXPOSURE LIQUID | | | STATIC EXPOSURE VAPOR | | | REMARKS |
|---|---|---|---|---|---|---|---|---|
| | | TIME IN DAYS | RATING [a] | REFERENCE | TIME IN DAYS | RATING [a] | REFERENCE | |
| **PLASTICS (CONT)** | | | | | | | | |
| Fluoro-green filled with ceramic | 55-60 | 30 | A | 15 | | | | |
| Fluorinated Propylene Co-polymer | | | | | | | | |
| Teflon (FEP) | 55-60 | 30 | C | 11 | | | | 1% to 3% $H_2O$, softened 3% to 10%, sample turned brown |
| | 63-67 | 30 | A | 4 | | | | |
| | 70-80 | 90 | A | 12 | | | | |
| | 160 | 7 | A | 12 | | | | |
| Polychloro-trifluoro-ethylene | | | | | | | | |
| Kel-F 300 Unplasti-sized | 55-60 | 30 | C | 11 | | | | Up to 3% $H_2O$, sample discolored and softened 16% |
| | 63-67 | 30 | A | 4 | | | | 30% loss in strength |
| | 70-80 | 70 | C | 1 | | | | Softened 76% |
| Annealed | 55-60 | 30 | C | 11 | | | | Sample discolored and softened |
| Genetron | | | | | | | | |
| GCX-3B | 55-65 | 30 | A | 19 | | | | |
| XE-2B | 55-65 | 30 | A | 19 | | | | |
| Trithene A | 70-80 | 90 | C | 12 | | | | Hardened 12% |
| Polyethylene | | | | | | | | |
| Low Density | 55-60 | 30 | C | 11 | | | | Sample turned brown |
| Iradiated | 55-60 | 30 | C | 15 | | | | Limited service |
| Hi Density | 55-60 | 30 | C | 15 | | | | Limited service |

a — Definitions of ratings are given on page 4-14.

TABLE 5.2 (CONT)

COMPATIBILITY OF NONMETALS WITH $N_2O_4$

| MATERIAL | TEMPERATURE DEGREES FAHRENHEIT | STATIC EXPOSURE | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | LIQUID | | | VAPOR | | | |
| | | TIME IN DAYS | RATING[a] | REFERENCE | TIME IN DAYS | RATING[a] | REFERENCE | REMARKS |
| PLASTICS (CONT) | | | | | | | | |
| Polyolefin | | | | | | | | |
| Raythene N (irradiated) | 55-85 | 60 | D | 19 | | | | Cracked |
| White and black insulation | 63-87 | 30 | A | 4 | | | | Slight dimensional change |
| Polypropylene | | | | | | | | |
| From Hercules | 55-60 | 30 | C | 11 | | | | Sample turned green |
| Polyamide-nylon | | | | | | | | |
| Zytel 101 | 55-80 | 30 | D | 11 | | | | Broke apart |
| Polyester | | | | | | | | |
| Mylar | 55-60 | 30 | D | 11,12 | | | | |
| Laminates-Glass | | | | | | | | |
| Silicone (composition unknown) | 55-60 | 30 | D | 11 | | | | Delaminated |
| Phenolic (composition unknown) | 55-60 | 30 | C | 11 | | | | Sample was bleached |
| Epoxy (composition unknown) | 55-80 | 30 | D | 11 | | | | Delaminated |

a — Definitions of ratings are given on page 4-14.

TABLE 5.2 (CONT)

COMPATIBILITY OF NONMETALS WITH $N_2O_4$

| MATERIAL | TEMPERATURE DEGREES FAHRENHEIT | STATIC EXPOSURE | | | | | | REMARKS |
|---|---|---|---|---|---|---|---|---|
| | | LIQUID | | | VAPOR | | | |
| | | TIME IN DAYS | RATING a | REFERENCE | TIME IN DAYS | RATING a | REFERENCE | |
| PLASTICS (CONT) | | | | | | | | |
| Polyester (composition unknown) | 55-60 | 30 | D | 11 | | | | Delaminated |
| Polyvinylidene Chloride | | | | | | | | |
| Saran | 55-60 | 30 | D | 11 | | | | Softened 17% |
| Polyformaldehyde | | | | | | | | |
| Delrin | 55-60 | 30 | D | 11 | | | | Reaction |
| Polycarbonate | | | | | | | | |
| Lexan | 55-60 | 30 | D | 11 | | | | Dissolved |
| Polyvinyl Fluoride | | | | | | | | |
| Teslar 30 | 63-67 | 30 | A | 4 | | | | |
| Polymethyl Methacrylate | | | | | | | | |
| Plexiglass | 55-60 | 30 | D | 11 | | | | Dissolved |
| Polyvinyl Chloride | | | | | | | | |
| Ultron | 70-80 | 90 | D | 12 | | | | Surface tacky |
| | 160 | 7 | D | 12 | | | | Crumbled |

a — Definitions of ratings are given on page 4-14.

TABLE 5.2 (CONT)

## COMPATIBILITY OF NONMETALS WITH $N_2O_4$

| MATERIAL | TEMPERATURE DEGREES FAHRENHEIT | STATIC EXPOSURE | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | LIQUID | | | VAPOR | | | |
| | | TIME IN DAYS | RATING[a] | REFERENCE | TIME IN DAYS | RATING | REFERENCE | REMARKS |
| PLASTICS (CONT) | | | | | | | | |
| Hydrocarbon Polymers | | | | | | | | |
| Formulas 24-27 (polybuta-diene) | 70-80 | 7 | D | 24 | | | | Crumbled |
| Formula 39 (polyethyl-ene) | 70-80 | 30 | C | 20 | | | | 26% volume swell, fair to good strength retention |
| Formulas 41-43 (iso-butylene co-polymers) | 70-80 | 7 | D | 24 | | | | Degraded |
| Formula 44 (isobutylene co-polymer) | 70-80 | 30 | D | 20 | | | | Degraded |
| Formulas 45-52 (iso-butylene co-polymers) | 70-80 | 7 | D | 24 | | | | Degraded |
| Formula 53 (polyethyl-ene + iso-butylene) | 70-80 | 30 | A | 20 | | | | 19% volume swell, good strength reten-tion |
| Formula 68 (polyethyl-ene + car-bon black) | 70-80 | 30 | D | 20 | | | | Degraded |
| Formulas 69-72 (polyisobu-tylenes) | 70-80 | 7 | D | 24 | | | | Formulas 69 and 70 blistered or deterior-ated, 71 and 72 swelled 145% |

a — Definitions of ratings are given on page 4-14.

TABLE 5.2 (CONT)

COMPATIBILITY OF NONMETALS WITH $N_2O_4$

| MATERIAL | TEMPERATURE DEGREES FAHRENHEIT | STATIC EXPOSURE | | | | | | REMARKS |
|---|---|---|---|---|---|---|---|---|
| | | LIQUID | | | VAPOR | | | |
| | | TIME IN DAYS | RATING[a] | REFERENCE | TIME IN DAYS | RATING[a] | REFERENCE | |
| PLASTICS (CONT) | | | | | | | | |
| Formulas 87-88 (iso-butylene co-polymers) | 70-80 | 30 | D | 20 | | | | 33%-39% volume swell, poor elastomeric properties |
| Formula 100 (isobutylene co-polymer) | 70-80 | 30 | D | 20 | | | | 41% volume swell, poor elastomeric properties |
| Formula 101 (isobutylene co-polymer) | 70-80 | 30 | B | 20 | | | | 13% volume swell, fair elastomeric proper-ties |
| Formula 102 (isobutylene co-polymer) | 70-80 | 30 | D | 20 | | | | 15% volume swell, poor elastomeric properties |
| Formulas 103-109 and 111 (isobu-tylene co-polymers) | 70-80 | 7 | D | 20 | | | | 27%-60% volume swell, very poor to fair elastomeric proper-ties, formula 106 has volume swell 23%, but poor elastomeric properties |
| DFDB 6169 (polyolefin) | 70-80 | 7 | D | 20 | | | | 45% volume swell, fair to good elastomeric properties |
| Formula 110 (polyolefin) | 70-80 | 7 | D | 20 | | | | 49% volume swell, fair to good elastomeric properties |
| Formula 116-117 (ethylene-propylene rubber) | 70-80 | 7 | D | 20 | | | | <25% volume swell, rated "D" because of poor elastomeric properties |
| Marlex 5003 (polyethylene + butene) | 70-80 | 30 | D | 20 | | | | Became brittle |

a — Definitions of ratings are given on page 1-14.

TABLE 5.2 (CONT)

COMPATIBILITY OF NONMETALS WITH $N_2O_4$

| MATERIAL | TEMPERATURE DEGREES FAHRENHEIT | STATIC EXPOSURE | | | | | | REMARKS |
|---|---|---|---|---|---|---|---|---|
| | | LIQUID | | | VAPOR | | | |
| | | TIME IN DAYS | RATING a | REFERENCE | TIME IN DAYS | RATING a | REFERENCE | |
| **BUTYL RUBBERS** | | | | | | | | |
| Enjay 268 | 55-60 | - | D | 15 | | | | |
| Enjay 551 | 55-60 | 30 | D | 11 | | | | Dissolved |
| Hycar 2202 | 55-60 | - | D | 15 | | | | |
| Garlock 22 | 55-60 | - | D | 15 | | | | |
| Parker 805-70 | 55-65 | 7 | D | 19 | | | | Became tacky |
| Parker XB-1235-10 | 70-80 | 7 | D | 1 | | | | 63% volume swell, softened 77% |
| **FLUORO RUBBERS** | | | | | | | | |
| Parker XV-1235-2 | 70-80 | 7 | D | 1 | | | | 500% volume swell, softened 85% |
| XV-1235-5 | 70-80 | 7 | D | 1 | | | | 430% volume swell, softened 92% |
| TFNM-TFE (Trifluoro-nitroso-methane tetrafluoro-ethylene) | 70-80 | 7 | D | 20 | | | | 174% volume swell, poor elastomeric properties, different oven cures reduce swell to 48% but retain poor elastomeric properties |
| Viton A | 55-60 | 30 | D | 11 | | | | Dissolved |
| Viton B (Stillman Ex 774M-1) | 63-67 | 30 | D | 4 | | | | 181% volume swell |
| Parker V494-7 | 63-67 | 30 | D | 4 | | | | 292% volume swell |

a -- Definitions of ratings are given on page 4-14.

## TABLE 5.2 (CONT)

## COMPATIBILITY OF NONMETALS WITH $N_2O_4$

| MATERIAL | TEMPERATURE DEGREES FAHRENHEIT | STATIC EXPOSURE | | | | | | REMARKS |
|---|---|---|---|---|---|---|---|---|
| | | LIQUID | | | VAPOR | | | |
| | | TIME IN DAYS | RATING[a] | REFERENCE | TIME IN DAYS | RATING[a] | REFERENCE | |
| FLUORO RUBBERS (CONT) | | | | | | | | |
| Formulas 75-79, 84, 85 and 94-99 | 70-80 | 7 | D | 20,24 | | | | Fluoro rubbers with added fillers did not reduce volume swell below 199%, poor to good strength retention |
| Kel-F 3700, 5500 | 55-65 | | D | 15,19 | | | | > 300% volume swell in 45 minutes |
| Stillman TH 1057 | 55-65 | 31 | D | 19 | | | | 205% volume swell |
| FLUORO SILICONE RUBBERS | | | | | | | | |
| LS 53 | 63-67 | 30 | D | 4, 15,20 | | | | > 200% volume swell |
| Formulas 55-67 and 80-83 | 70-80 | 7 | D | 20,24 | | | | Fluorosilicone rubbers with added fillers did not reduce volume swell below 120% |
| LS-63 | 63-67 | 30 | D | 4 | | | | 172% volume swell |
| Hadbar Series 58789-23 | 70-80 | 7 | D | 1 | | | | > 185% volume swell |
| 58789-23GT | 63-67 | 30 | D | 4 | | | | 145% volume swell |
| MISCELLANEOUS RUBBERS | | | | | | | | |
| Buna N | 55-60 | - | D | 15 | | | | |
| Neoprene | 55-60 | - | D | 15 | | | | |

a — Definitions of ratings are given on page 4-14.

TABLE 5.2 (CONT)

COMPATIBILITY OF NONMETALS WITH $N_2O_4$

| MATERIAL | TEMPERATURE DEGREES FAHRENHEIT | STATIC EXPOSURE | | | | | | REMARKS |
|---|---|---|---|---|---|---|---|---|
| | | LIQUID | | | VAPOR | | | |
| | | TIME IN DAYS | RATING[a] | REFERENCE | TIME IN DAYS | RATING[a] | REFERENCE | |
| MISCELLA-NEOUS RUBBERS (CONT) | | | | | | | | |
| Hypalon | 55-60 | - | D | 15 | | | | |
| Cohrlastic 500 (Silicone) | 55-60 | - | D | 15 | | | | |
| Silicone O-ring with Kel-F Cover | 55-65 | 63 | D | 19 | | | | Core shredded |
| LUBRICANTS | | | | | | | | |
| DC 11 | 63-67 | 14 | C | 4 | 14 | C | 4 | Washed off in liquid, partly in vapor |
| DC Hi Vac | 63-67 | 14 | C | 4 | 14 | C | 4 | Washed off in liquid, partly in vapor |
| | 55-60 | 30 | D | 11 | | | | Dissolved |
| Rayco -30 Grease | 55-60 | 30 | D | 11 | | | | Decomposed |
| Kel-F 90 | 55-60 | 30 | D | 11 | | | | Dissolved |
| Polygylcol Oils | 63-67 | 14 | D | 4 | | | | Reaction |
| L-1111-oil | 63-67 | 14 | C | 4 | | | | 2 - Phase layer washed off |
| Molykote Z | 55-60 | 30 | A | 11 | | | | Satisfactory |
| Drilube 703 | 55-60 | 30 | A | 11 | | | | Satisfactory |
| Electrofilm 66-C | 55-60 | 30 | A | 11 | | | | Satisfactory |
| TMSF-1,2,3 | 55-60 | 30 | D | 11 | | | | Crystallized |
| QC-2-0033 QC-2-0026 Dow | 55-60 | 30 | D | 11 | | | | Broken up |

a — Definitions of ratings are given on page 4-14.

TABLE 5.2 (CONT)

COMPATIBILITY OF NONMETALS WITH $N_2O_4$

| MATERIAL | TEMPERATURE DEGREES FAHRENHEIT | TIME IN DAYS[a] | RATING[a] | REFERENCE | TIME IN DAYS[a] | RATING[a] | REFERENCE | REMARKS |
|---|---|---|---|---|---|---|---|---|
| | | | STATIC EXPOSURE LIQUID | | | VAPOR | | |
| **LUBRICANTS (CONT)** | | | | | | | | |
| Rayco -32 Grease | 55-60 | 30 | D | 11 | | | | Decomposed |
| Halocarbon Grease | 63-67 | 14 | C | 4 | 14 | C | 4 | Washed off in liquid, partly in vapor |
| Nordcoseal 147 and 421 | 70-80 | – | C | 4,19 | | | | Used satisfactorily for hardware assembly |
| **THREAD SEALANTS** | | | | | | | | |
| $N_2O_4$ sealant | 70-80 | 30 | A | 1 | | | | Satisfactory |
| | 160 | 7 | A | 1 | | | | Satisfactory |
| Reddy Lube | | | | | | | | |
| 100 | 63-67 | 14 | A | 4 | 14 | A | 4 | Satisfactory |
| 200 | 63-67 | 14 | A | 4 | 14 | A | 4 | Satisfactory |
| Waterglass Graphite | 63-67 | 14 | A | 4 | 14 | A | 4 | Satisfactory |
| Vydax A | 63-67 | 14 | C | 4 | 14 | C | 4 | Partially washed off |
| **ADHESIVES** | | | | | | | | |
| Armstrong A-6 | 55-60 | 30 | D | 11 | | | | Fell apart |
| EC 847 | 35-60 | 30 | D | 11 | | | | Fell apart |
| HT 424 | 55-60 | 30 | D | 11 | | | | Fell apart |
| **CERAMICS** | | | | | | | | |
| Temporell 1500 | 55-60 | 30 | C | 11 | | | | Slight precipitate |

a — Definitions of ratings are given on page 4-14.

TABLE 5.2 (CONT)

COMPATIBILITY OF NONMETALS WITH $N_2O_4$

| MATERIAL | TEMPERATURE DEGREES FAHRENHEIT | STATIC EXPOSURE | | | | | | REMARKS |
|---|---|---|---|---|---|---|---|---|
| | | LIQUID | | | VAPOR | | | |
| | | TIME IN DAYS | RATING[a] | REFERENCE | TIME IN DAYS | RATING[a] | REFERENCE | |
| **CERAMICS (CONT)** | | | | | | | | |
| Saucreisen P-1 | 55-60 | 30 | A | 11 | | | | Satisfactory |
| Sauereisen 31 | 55-60 | 30 | C | 11 | | | | Slight precipitate |
| Sauereisen 47 | 75 | - | D | 4 | | | | Dissolved within 10 minutes |
| Rockflux | 75 | - | C | 4 | | | | $N_2O_4$ was absorbed, slight lifting from concrete |
| **PAINTS** | | | | | | | | |
| Epoxy No. 1 | 55-60 | 30 | D | 11 | | | | Dissolved |
| Modified Epoxy No. 5 | 55-60 | 30 | D | 11 | | | | Dissolved |
| Epoxy No. 7 | 55-60 | 30 | D | 11 | | | | Dissolved |
| Epoxy No. 9 | 55-60 | 30 | D | 11 | | | | Stripped off |
| Epoxy 6809 | 55-60 | 30 | D | 11 | | | | Dissolved |
| Alkyd No. 4 | 55-60 | 30 | D | 11 | | | | Dissolved |
| Polyurethane | 55-60 | 30 | D | 11 | | | | Stripped |
| Catalac | | | | | | | | |
| Primer and Finished on Mild Steel | 63-67 | 10 | D | 4 | | | | Paint lifted within minutes |
| Improved | 63-67 | - | D | 4 | | | | Paint lifted, and blistered within 2 minutes |
| Acrylic Nitro-Cellu-lose | 55-60 | 30 | D | 11 | | | | Dissolved |
| Vinyl | 55-60 | 30 | D | 11 | | | | Blistered |

a — Definitions of ratings are given on page 4-14.

TABLE 5.2 (CONT)

COMPATIBILITY OF NONMETALS WITH $N_2O_4$

| MATERIAL | TEMPERATURE DEGREES FAHRENHEIT | STATIC EXPOSURE | | | | | | REMARKS |
|---|---|---|---|---|---|---|---|---|
| | | LIQUID | | | VAPOR | | | |
| | | TIME IN DAYS | RATING | REFERENCE | TIME IN DAYS | RATING | REFERENCE | |
| **PAINTS (CONT)** | | | | | | | | |
| Primer MIL-P-6889 | 50-60 | 30 | D | 11 | | | | Stripped off |
| Tygon A | 75 | - | D | 4 | | | | Blistered within 30 minutes |
| Co-Polymer P-300G | 75 | - | D | 4 | | | | Dissolved in 2 minutes |
| CA 9747 Primer | 75 | - | D | 4 | | | | Reacted and dissolved within 3 minutes |
| Corrosite Clear 581 | 75 | - | D | 4 | | | | Blistered within 30 minutes |
| **POTTING COMPOUNDS** | | | | | | | | |
| PR 1422 | 55-60 | 30 | D | 11 | | | | Dissolved |
| RTV 20 | 55-60 | 30 | D | 11 | | | | Dissolved |
| Epon 828 | 55-60 | 30 | D | 11 | | | | Dissolved |
| Paraplex P-43 | 55-60 | 30 | D | 11 | | | | Dissolved |
| Proseal 793 | 55-60 | 30 | D | 11 | | | | Dissolved |
| Fairprene 5150 | 55-60 | 30 | D | 11 | | | | Partially dissolved |
| Crystal M & CF | 55-60 | 30 | C | 11 | | | | Limited use only |

a — Definitions of ratings are given on page 4-14.

TABLE 5.2 (CONT)

COMPATIBILITY OF NONMETALS WITH $N_2O_4$

| MATERIAL | TEMPERATURE DEGREES FAHRENHEIT | STATIC EXPOSURE | | | | | | REMARKS |
|---|---|---|---|---|---|---|---|---|
| | | LIQUID | | | VAPOR | | | |
| | | TIME IN DAYS | RATING a | REFERENCE | TIME IN DAYS | RATING a | REFERENCE | |
| MISCELLA-NEOUS | | | | | | | | |
| Johns Mansville No. 60 | 55-65 | 7 | D | 19 | | | | Salts formed |
| Graphitar No. 2 | 55-65 | 30 | A | 19 | | | | |
| No. 50 | 55-65 | 30 | A | 19 | | | | |
| Garlock 900 | 55-90 | 30 | D | 11,19 | | | | Sample delaminated |

a — Definitions of ratings are given on page 4-14.

## 5.3   EFFECTS OF $N_2O_4$ ON MATERIALS OF CONSTRUCTION

Table 5.3 mentions materials frequently used for construction. Included are the compatibility results of short exposures to $N_2O_4$ vapors and to watered $N_2O_4$. Reference 4 gives the details of these tests in which coatings and/or surface treatments were applied to various materials to ascertain resistance to $N_2O_4$ spills. Of the organic coatings, none exhibit sufficient resistance to $N_2O_4$. Water glass protects concrete from $N_2O_4$ and from nitric acid which is formed when $N_2O_4$ combines with water.

### TABLE 5.3

### COMPATIBILITY OF CONSTRUCTION MATERIALS WITH $N_2O_4$

| Material | Temperature (°F) | Exposure Time | Remarks |
|---|---|---|---|
| Birch Wood | 75 | 30 min | Surface darkened; attacked at $H_2O$-$N_2O_4$ interface |
| Concrete | | | |
| Bare | 75 | 1 hr 42 min | Concrete attacked |
| Coated with water glass | 75 | 1 hr | No apparent reaction; affords protection |
| Coated with water glass and floor enamel (Esco Brand 41138) | 75 | 30 min | Reaction at $H_2O$-$N_2O_4$ interface after 6 minutes; stripped to water glass |
| Coated with water glass and Chex-Wear floor enamel | 75 | 3 min | Only paint removed |
| Coated with Rockflux | 75 | 1 hr 15 min | $N_2O_4$ absorbed; adhesion weakened; material turned white |
| Mild Steel Coated with | | | |
| Tygon K paint | 75 | 20 min | Paint blistered |
| Catalac, improved | 75 | 10 min | Paint blistered; lifted when totally immersed |
| Co-Polymer P-200G | 75 | 2 min | Dissolved immediately |
| Sauereisen 47 (4 coatings) | 75 | 10 min | Dissolved |
| CA9747 Primer Paint | 75 | 2 min | Reaction and discolored immediately |
| Corrosite Clear 581 | 75 | 30 min | Blistered |

5.4    EFFECTS OF CONTAMINANTS ON $N_2O_4$

Traces of type 347 SS, 6061 aluminum alloy, and lint may be found as contaminants during missile systems manufacturing. To determine the effects of such contaminants on $N_2O_4$, quantities of lint and shavings of type 347 SS and 6061 aluminum alloy were exposed to $N_2O_4$ at 70°F for seven days. No severe pressure build-ups were encountered during these tests and the $N_2O_4$ composition was unchanged (Reference 19). Water is a serious contaminant since it combines with $N_2O_4$ to form dilute nitric acid which exhibits more-corrosive properties than $N_2O_4$. Also, the presence of organic compound, such as alcohols, acetones, and gasoline, are undesirable contaminants because of their reactivity with $N_2O_4$.

# SECTION 6.0

# PROPELLANT HANDLING

SECTION 6.0

PROPELLANT HANDLING

## 6.1 FIRE FIGHTING

The 50/50 fuel blend is flammable in both liquid and vapor states. Since the vapor over the fuel blend at 72°F is predominantly UDMH (Reference 3), the flammability hazards of the mixture are the same as for UDMH. Based upon the lower limit of flammability of UDMH, 2.3 volume percent in air at one atmosphere and 5°F (Reference 23), the fuel blend vapors are flammable in air in concentrations from 2.3 to 100 volume percent. Thus, mixtures within these limits can be ignited by electric spark, hot wire, or open flame.

Large quantities of water should be used to extinguish fuel blend fires. Based upon the flash and fire point data reported in Section 2.0 of this handbook, a dilution of three volumes of water to two volumes of the fuel blend is required to increase the flash and fire point temperature in air to 160°F.

Atlantic Research Corporation (Reference 25) has ignited liquid N$_2$H$_4$ and UDMH at 80°F with a jet of N$_2$O$_4$ vapor. Similar tests were conducted with each fuel diluted with water until no ignition occurred. No ignition occurred when the N$_2$H$_4$ was less than 60 volume percent and when the UDMH was less than 70 volume percent. Based upon these tests and the flash and fire points data given in Section 2.0 of this handbook, all fuel blend spills at 80°F should be diluted with water to a concentration less than 60 volume percent. This dilution will preclude fires caused by electric spark, hot wire, open flame, or N$_2$O$_4$ vapors.

Atlantic Research Corporation also reported that water sprays directed at fuel fires supported by air or by N$_2$O$_4$ vapors are more effective extinguishing agents than foams.

Nitrogen tetroxide is a stable, nonflammable, shock-insensitive compound. Alone, N$_2$O$_4$ will not burn, but its vapors will support combustion. If fire supported by N$_2$O$_4$ occurs, shut off the N$_2$O$_4$ supply and use a extinguisher that is compatible with the burning material.

The explosivity of the liquid phase reaction between the 50/50 fuel blend and N$_2$O$_4$ is discussed under Flammability and Explosivity, Section 8.0 of this handbook.

6.2    FUEL MIXING

As mentioned under Physical Properties of 50/50 Fuel Blend, Section 2.0 of this handbook, UDMH and $N_2H_4$ are miscible in all proportions. However, because their densities differ, they are easily layered, UDMH above the $N_2H_4$.

With sufficient agitation, the $N_2H_4$ and UDMH are readily mixed so that the smallest unit volume of the mixture contains as many molecules of each component as every other unit volume. Upon attaining this state of mixing, there is no tendency whatever for the compounds to separate provided that the more-volatile UDMH is not permitted to evaporate from the vessel. The same forces that cause the layered components to mix will assure the permanence of the completely blended mixture. This does not mean that $N_2H_4$ and UDMH cannot be separated, but separation can be accomplished only by the transfer of energy in certain types of physical processes (fractional distillation) and chemical processes (formation of chemical derivatives) (Reference 1).

Under conditions where only partial mixing has occurred, strata of different compositions and densities can exist. Gravity will cause these strata to rise and fall in relation to each other. However, this phenomenon cannot be interpreted as a separation of the compounds because complete mixing was never attained. Thus, any condition short of complete blending cannot be tolerated and the measures required to effect complete blending must not be neglected (Reference 1).

When $N_2H_4$ and UDMH are mixed, small bubbles of dissolved gas are formed, there is a decrease in temperature, and the mixture occupies a smaller volume than the original combined volume of both. The shrinkage in volume is partly due to the drop in temperature; however, freshly mixed fuel blend that is allowed to warm to the temperature of the unmixed components still incurs a shrinkage of about 1.6%. The additional shrinkage is due to some form of loose bonding between the $N_2H_4$ and UDMH molecules which results in a more-compact molecular arrangement when the two are mixed (Reference 1).

Quantities of fuel were mixed using various mixing techniques as discussed in the following paragraphs.

6.2.1    Mixing by Agitation

Approximately 35 gallons of the fuel blend were mixed by adding $N_2H_4$ to UDMH in a type 304 SS 55-gallon drum (Reference 2). Mixing was accomplished by first rolling the drum on its side then end over end for 15 minutes.

6.2.2    Mixing by Diffusion

Approximately one pint of $N_2H_4$ was added to an equal amount of UDMH in a glass container. The fuel mixture remained undisturbed except for sampling. After 50 days, a homo-

geneous mixture through diffusion was obtained (Reference 4). This method is not recommended for use because of the time element and the uncertainty of its effectiveness when blending large quantities.

### 6.2.3 Mixing by Mechanical Stirring

Approximately one quart of fuel blend was mixed in a glass container. Mixing was accomplished in a nitrogen atmosphere with a glass stirrer turning at 760 rpm for five minutes and 1 rpm for 72 hours. The ratio of the area of the stirrer (2.5 in.$^2$) to the volume (48.7 in.$^3$) of the blend was 0.05. If this technique is feasible for large-scale mixing, it can be used with success.

### 6.2.4 Mixing by Gas Bubbling

Approximately one quart of fuel blend was mixed successfully with a nitrogen gas stream. This method is not recommended because UDMH losses are incurred during the operation (Reference 4).

### 6.2.5 Mixing by Impingement

A mixing chamber similar to that described by W. R. Ruby (Reference 26) was used to mix laboratory quantities of the fuel blend. Photographs of the apparatus and a detailed procedure is presented in Reference 4. Mixing was accomplished when two streams of UDMH impinged tangentially with two streams of $N_2H_4$.

Wyle Laboratories (Reference 37) successfully mixed approximately 41,000 pounds (110 drums) of the fuel blend by recirculating the fuels through a blender (which caused mixing similar to the impingement technique) and into a storage tank. Following the initial transfer of each fuel into the storage tank, two centrifugal pumps provided continuous circulation through the blender for approximately two hours before mixing was accomplished.

Aerojet-General Corporation (Reference 1) also has blended thousands of gallons of the fuel blend by pumping the fuel components simultaneously from each tank into a concentric nozzle containing a swirling mechanism to enhance mixing, and then into the fuel blend storage tank.

## 6.3 FREEZE AND THAW OF 50/50 FUEL BLEND

A laboratory test was conducted to determine the effect of alternate freezing and thawing of the fuel blend. The apparatus used, a description of the test procedure, and the detailed test results are presented in Reference 2. Results of these tests indicate that the fuel blend separates when subjected to freezing and thawing conditions. When freezing occurs, the $N_2H_4$ solidifies

first because its freezing point is 55°F. The solid $N_2H_4$ particles tend to fall to the bottom because they are more dense than UDMH. Since analyses indicate that separation occurs, fuel blend subjected to freezing point temperature should be re-mixed prior to use.

## 6.4   STORAGE

Fuel blend was stored for six months at 60° ±5°F in a two-quart 1100 aluminum alloy tank and a one-quart Pyrex glass bottle. No fuel decomposition was detected in either container (Reference 4).

Spectral analyses of the fuel blend in a one-quart Pyrex glass bottle gave no evidence of fuel blend separation after three months (Reference 4).

The fuel blend was stored in sealed Pyrex glass ampules at 200°F for 12 weeks (References 2 and 4). Employing the weight loss technique for measuring fuel decomposition resulted in inconclusive data. However, spectral analyses and visual examination of the fuel indicated no significant change after the storage period. Also, no positive pressure was detected when each ampule was opened. These observations indicate no decomposition.

Low-temperature and high-temperature storage tests were conducted with $N_2O_4$. Allied Chemical Corporation reports that $N_2O_4$ was stored out-of-doors in a small carbon steel container for nine years at temperatures ranging from 68° to 100°F. Post-test analyses showed no change in propellant composition.

In another test, $N_2O_4$ was stored in 10-gallon tanks made from PH 15-7 Mo stainless steel and 6061-T6 aluminum alloy for six months at temperatures ranging from 0° to 100°F. Chemical analyses after the test showed no change in propellant composition and a visual examination of the interior of the tank indicated no metal attack (Reference 19).

For three months, $N_2O_4$ was stored at 270° ±10°F in two-quart tanks made from PH 15-7 Mo and 347 SS and from 6061-T6 aluminum alloy. The $N_2O_4$ remained unchanged except for a trace of nitric acid found by spectral means and an indication of the entry of water. Visual examination of the tanks disclosed salt deposits.

In the foregoing high-temperature storage tests, moisture was prevented from entering the system to preclude the formation of nitric acid from the $N_2O_4$. The acid in turn would have reacted with the stainless steel and aluminum alloy to form nitrates that are insoluble in $N_2O_4$.

Because titanium tends to react with oxidizers such as RFNA (Reference 27) and fluorine (Reference 28) to form unstable compounds which violently decompose, a one-month storage test of $N_2O_4$ in a titanium tank (C120AV) was conducted at cycling temperatures between 90° and 150°F (Reference 19). No abnormal pressures were detected during the test period; at the con-

clusion of the test, a 50-pound weight was dropped from a height of two feet onto the tank to determine if shock-sensitive deposits had formed. No reaction to this shock was observed. The chemical composition of the $N_2O_4$ remained unchanged and examination of the tank interior showed no signs of deposits.

## 6.5  CLEANING AND FLUSHING

Field experience with missile systems indicates that components such as valves, flow regulators, lines, fittings, and filters which have been serviced and/or used with propellants should be decontaminated prior to being set aside for down-time or storage periods.

Bell Aerosystems evaluated various flush procedures for 90 days storage using RASCAL thrust chamber bipropellant valves (Reference 4). A cross-section of the valve and a list of the flush procedures are given in Reference 2. The best flush procedure for the oxidizer system proved to be a tri-liquid flush and, for the fuel system, an alcohol flush.

The tri-liquid flush procedure involves water inhibited with chromium trioxide, methanol, and methylene chloride. The water dissolves any metal nitrate salts and removes excess $N_2O_4$; the methanol combines with the water and with continuous cycling replaces the water; and the methylene chloride combines with residual methanol. The final purge with warm nitrogen easily vaporizes the low-boiling methylene chloride.

For the fuel system, an isopropanol or methanol flush procedure is recommended. The fuel blend is soluble in either of these alcohols. Briefly, the flush procedure is as follows:

(1) Drain the propellants and purge the valve with nitrogen gas.

(2) Flush the oxidizer system with inhibited water, cycling the valve ten times (15 seconds open and 15 seconds closed).

(3) Flush the fuel system with isopropanol or methanol, cycling the valve ten times (15 seconds open and 15 seconds closed).

(4) Flush the oxidizer system with methanol, cycling the valve ten times (15 seconds open and 15 seconds closed).

(5) Flush the oxidizer system with methylene chloride, cycling the valve ten times (15 seconds open and 15 seconds closed).

(6) Purge the oxidizer and fuel systems dry with warm nitrogen (140° to 160°F), cycling the valve ten times (15 seconds open and 15 seconds closed).

The cycling time may be extended, depending upon the complexity of the systems.

Aerojet-General Corporation (Reference 1) is evaluating a liquid flush procedure for flight test engines. Triethanolamine solutions with various additives are being used to neutralize residual oxidizer and hydroxyacetic acid solution, and various additives are being used to neutralize the residual fuel. The flush procedure they used after acceptance testing is as follows:

(1) Drain propellants.

(2) Open thrust chamber valves and place plug in nozzle of the thrust chamber.

(3) Fill and drain fuel and oxidizer systems simultaneously with water.

(4) Fill and drain oxidizer system three times with alkaline (triethanolamine) neutralizing solution.

(5) Fill and drain fuel system three times with acid (hydroxyacetic) neutralizing solution.

(6) Fill and drain fuel and oxidizer systems simultaneously with water.

(7) Fill and drain fuel and oxidizer systems simultaneously with alcohol for drying.

(8) Purge fuel and oxidizer systems dry with hot nitrogen gas.

Several pickling and degreasing procedures were applied to type 316 SS and 2014-T6 aluminum alloy coupons that were partly immersed in the 50/50 fuel blend at 160°F for about two months. Some of the aluminum alloy coupons were welded. These tests were conducted to determine whether or not certain degreasers and/or pickling solutions would result in severe discoloring of the metal coupons or the fuel blend (Reference 4).

Three pickling procedures and three degreasers were applied to 2014-T6 coupons. The pickling procedures used are described in Reference 4. The degreasers used were trichlorethylene, trichlorethane, and Arseco (a safety solvent principally containing kerosene). Each test coupon exhibited good corrosion and was assigned an "A" rating. The fuel blend was unaffected and only slight staining was detected on the surface of the coupon.

Type 316 SS welded and unwelded coupons were acid-pickled and then degreased with trichlorethylene, trichlorethane and Arseco. The pickling procedure used is described in Reference 4. Again, the fuel blend was unaffected and the corrosion rates merited an "A" rating. Slight staining was observed in the vapor phase.

# SECTION 7.0

## SAFETY

SECTION 7.0

SAFETY

## 7.1 NOMINAL 50/50 FUEL BLEND

### 7.1.1 Health Hazards

Generally it is suggested that any handling mishaps or similar situations be treated as though caused by UDMH or $N_2H_4$ alone, depending upon which of the two fuels causes the more serious effects.

Arthur D. Little, Inc. has reported on fuel blend toxicity (Reference 29). Animal experiments conducted at ADL failed to show significant synergistic effects caused by the combined toxicity of UDMH and $N_2H_4$. The M.A.C.[a] value for $N_2H_4$ is 1 ppm and for UDMH it is 0.5 ppm. ADL graphically illustrated that when the vapor is contaminated with 0.25 ppm UDMH, the maximum allowable $N_2H_4$ is 0.5 ppm (see Figure 7.1). Regarding short-term exposure, Dr. Leslie Silverman of the Harvard Medical School of Public Health has suggested that the M.A.C. value can be exceeded safely by a factor of ten with the 50/50 fuel blend for a 10-minute period. Dr. E. C. Wortz (Reference 35) of The Martin Company has calculated data to show that the M.A.C. value can be exceeded by a factor of five for each fuel separately. Dr. Wortz's data is considered as safe short-term exposure limits.

Studies of the effects from repeated exposure of rodents and dogs to UDMH vapor were conducted at the Army Chemical Center (Reference 42) to obtain data for estimating the quantity of toxicant to which man may be exposed without harmful effects. Based upon the results of these experiments, the M.A.C. of UDMH vapor for man should be well below 5 ppm. Until more data and experience are available, 0.5 ppm should be used as a guide to good industrial handling and safe practice.

Experience with human exposure to $N_2H_4$ and UDMH is limited, but cases of delayed and possibly cumulative conjunctivitis have been reported among men in plants manufacturing $N_2H_4$. These employees complained of nausea, dizziness, and headache. The occurrence of dermatitis also was reported.

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a-Maximum Allowable Concentration. These represent values to which man can be exposed for a normal working day, day after day, without adverse effects upon his health.

| PROPELLANT | M.A.C.(ppm) |
|---|---|
| UDMH | 0.5 |
| $N_2H_4$ | 1.0 |
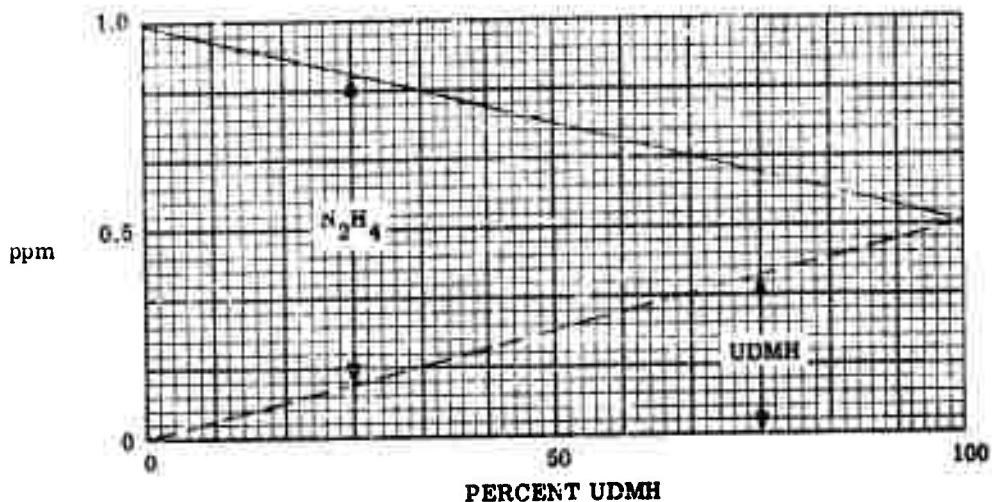


Figure 7.1. Combined Tolerable Vapor Contamination

In sufficient amounts, UDMH is toxic by inhalation, ingestion, and skin contact producing several significant systemic effects. In addition, it produces local irritating effects upon the eyes and the respiratory tract; UDMH has little or no local effect on the skin, but is readily absorbed into the body by this route.

### 7.1.2 Protective Clothing

Personnel handling the fuel blend should wear protective clothing. In general, rubber suits, boots and gloves, and hoods will suffice. The recommended protective clothing is:

(1) Boots and gloves – GRS rubber.

(2) Gloves, vinyl-coated, type R-1, under specification MIL-G-4244 (Reference 30).

(3) Gloves, Bluettes, DuPont neoprene rubber, Pioneer Rubber Company, Willard, Ohio.

(4) Gloves, Edmont, Cadet style, 7897, Edmont Inc., Coshocton, Ohio.

(5) Suit, vinyl-coated fiberglass, inner type MA-1, MIL-S-4553 (USAF) (Reference 30).

(6) Suit, MIL-S-12527 (QMC) (Reference 30).

(7) Polyethylene clothing may be used (Reference 30).

(8) Fiberglass clothing impregnated with Teflon or Kel-F (Reference 30).

When entering an area where a high concentration of fuel blend vapor is present, a self-contained air source such as a Scott Air-Pack should be worn. A canister-type protective breathing apparatus is effective up to 30 minutes for contamination levels up to 10,000 ppm (Reference 29).

Large quantities of the fuel blend should be transferred in clean, closed metal systems. The fuel blend should be blanketed with nitrogen at all times.

### 7.1.3 First Aid

Skin areas splashed with the fuel blend should be washed copiously with water. The eye, if contaminated, should be flushed copiously and thoroughly with water.

Personnel suspected of inhaling fuel vapor poison should leave the contaminated area and breathe deeply of fresh air. If fuel is taken internally, induce vomiting. Individuals over-exposed should be examined by a physician; regular handlers should be examined by a physician periodically.

### 7.1.4 Disposal

Leaks or spills of fuel blend should be dealt with only by personnel wearing adequate protective equipment. Dilution with minimum quantities of water, flushing down drains into catch basins, should be accomplished as soon as possible. Minimum quantities of water are recommended so that the diluted fuel eventually may be disposed of by burning.

During testing at Bell under another program, an undetected UDMH spill drained into a nearby waterway. Shortly thereafter, dead fish were seen floating on the surface of the water. State water pollution authorities attributed the dead fish to UDMH which eventually led to extensive testing by the Water Pollution Control Board and the U. S. Public Health Service. These tests revealed that one ppm of UDMH and/or $N_2H_4$ had an adverse effect upon fish (Reference 31). Because of this, steps were taken at Bell to destroy UDMH and/or $N_2H_4$. Subsequently, calcium hypochlorite[a] was used for the chemical destruction of small quantities of UDMH and $N_2H_4$ prior to draining into a public waterway.

Because the fuel blend in water can have adverse effects on fish and animals, it should not be added deliberately to drainage ditches or ponds. Bulk quantities should be collected in suitable containers for burning. When the fuel blend enters drainage systems by accident, it must be reduced to safe limits by addition of a chemical such as calcium hypochlorite which will decompose the blend (Reference 32).

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a — Calcium Hypochlorite Needed: 1.6 lb/gal of solution containing 1% by weight $N_2H_4$; 0.8 lb/gal of solution containing 1% by weight UDMH.

R. W. Drake of The Martin Company has prepared a procedure for fuel blend disposal. When a water solution contains 1% or less fuel blend, calcium hypochlorite is used to destroy the fuel chemically; fuel concentrations in the range of 1% to 40% are burned in a furnace; fuel concentrations greater than 40% are burned in air.

### 7.1.5 Detection Devices

A portable detection kit for fuel, manufactured by the Mine Safety Appliance Company of Pittsburgh, uses a colorimetric test specific for UDMH. This device can measure quantities of UDMH in waste water and air samples (Reference 1). The range of this detector is 0 to 10 ppm.

Another device, manufactured by the American Systems, Inc., is reported capable of measuring small quantities of UDMH or $N_2H_4$ in the order of 0.25 ppm.

However, these devices have not been fully evaluated. One problem in particular concerns the effectiveness of the instruments when both fuel and oxidizer vapor come in contact with the sensing media simultaneously.

## 7.2 $N_2O_4$ OXIDIZER

### 7.2.1 Health Hazards

Dr. Tamas of the Aerospace Medical Division of WADD has indicated that, at vapor concentrations of 100 ppm or lower, $N_2O_4$ does not exist for purposes of practical measurement, but the vapors are primarily $NO_2$. Even at concentrations as high as 10,000 ppm, only about 0.1% is $N_2O_4$ at room temperature and one atmosphere. Thus, as mentioned in the section on Detection Devices later in this handbook, instruments that are sensitive to $NO_2$ vapors are desirable.

Liquid $N_2O_4$ spillage on the skin or splashing in the eyes causes burns similar to those caused by 60% to 70% nitric acid. Brief contact of the liquid with the skin or other tissues results in yellow staining; if the contact is more than momentary, a severe chemical burn will result. The $N_2O_4$ vapors that contact the skin are less harmful than liquid contact for a comparable period of time. A stinging sensation results on the skin similar to that caused by nitric acid fumes. If splashed in the eyes, $N_2O_4$ can cause blindness. Taken internally, the burn can be sudden and severe, resulting in death (Reference 33).

Because of its toxic effects, inhalation of $N_2O_4$ vapors is normally the most serious hazard in the handling operations. The M.A.C. of this vapor is expressed as five parts of $NO_2$ per one million parts of air (2.5 ppm as $N_2O_4$) (Reference 34). Dr. Leslie Silverman (Reference 29) of the Harvard Medical School of Public Health has suggested that the M.A.C. value can be exceeded safely by a factor of five for a 10-minute period. Also, Dr. E. C. Wortz (Reference 35)

of The Martin Company has compiled data for short-term exposures to $N_2O_4$; for a 10-minute period, the M.A.C. value also may be exceeded by a factor of five. The Nitrogen Division of Allied Chemical (Reference 36) reports that a person was exposed to 158 ppm of $NO_2$ for 10 minutes without apparent effects; this value exceeds the M.A.C. by a factor of 30. Thus, Dr. Silverman's and Dr. Wortz's data appears to be safe values for short-term exposures.

### 7.2.2 Protective Clothing

Personnel handling $N_2O_4$ should wear protective clothing. Rubber suits, boots and gloves, and hoods will suffice. The protective clothing previously listed in the section on fuel blend safety is satisfactory for use with $N_2O_4$. Personnel at Wyle Laboratories (Reference 37) while wearing two-piece protective suits developed nitric acid burns around exposed wrists and ankles. These burns resulted from nitric acid formation when $NO_2$ vapors and moisture came in contact with the skin. Recurrence of this was prevented by taping the jacket sleeves and pants cuffs to the wrists and ankles.

### 7.2.3 First Aid

When liquid or vapor $N_2O_4$ comes in contact with the skin, immediately wash with large quantities of water. When splashed into the eyes, flush the eyes with water continously for 15 minutes, with a fellow employee assisting the injured by holding the eye open. Medical assistance should be summoned immediately. Administration of anything else, such as neutralizing agents, should be done only at the direction of a physician.

Persons exposed to excessive $N_2O_4$ fumes should be removed from the contaminated area immediately. The patient should be carried and not allowed to walk because exertion increases the effects of pulmonary edema. Administration of oxygen by trained personnel is desirable. Personnel exposed seriously should be removed to a hospital.

Swallowing of $N_2O_4$ should be treated by drinking large amounts of water (or milk, if available); medical attention should be summoned at once.

### 7.2.4 Disposal

Small and large quantities of $N_2O_4$ can be vented slowly out-of-doors through elevated stacks. Rocketdyne uses a 50-foot stack from 15,000-gallon tanks for venting when atmospheric conditions are favorable. The Nitrogen Division of Allied Chemical Corporation indicates that quantities of $N_2O_4$ can be drained or pumped into a pond where the $N_2O_4$ can be neutralized with soda ash, or allowed to boil off, provided that the area is not populated. Neutralization should take place prior to dumping into a waterway. Because water is only slightly soluble in $N_2O_4$, and $N_2O_4$

is heavier, this process is time-consuming; the $N_2O_4$ might remain at the bottom and slowly convert to nitric acid. In addition, large quantities of $N_2O_4$ may be disposed of by burning with a fuel such as kerosene. Rocketdyne also burns $N_2O_4$ near test stand locations with liquid petroleum gas.

### 7.2.5 Detection Devices

There are several instruments available specifically for detecting the presence of oxides of nitrogen in air. The Kitagawa Company manufactures a portable detector for air sampling. A dry reagent turns yellowish brown at $NO_2$ concentrations of approximately 2.5 ppm. This instrument is distributed by the Union Industrial Equipment Corporation, Port Chester, New York (Reference 1). Mine Safety Appliance Company, Kruger Instrument Company, and American Systems Incorporated manufacture a recording device for detecting oxides of nitrogen in the order of 1 ppm. However, these devices have not been fully evaluated.

# SECTION 8.0

# FLAMMABILITY AND EXPLOSIVITY

SECTION 8.0

FLAMMABILITY AND EXPLOSIVITY

8.1 FLAMMABILITY

The introduction of hypergolic fuel-oxidant systems into the missile propulsion field has created many new problems. These problems arise in part from the hazards associated with the handling and storage of the fuel and oxidant in close proximity; accidental or premature contact of fuel and oxidant (liquid or vapor phase) can result in a sudden energy release. In an effort to understand the behavior of such systems under accidental spill conditions, the Bureau of Mines and Bell Aerosystems Company agreed to study the 50/50 fuel blend-$N_2O_4$ system. A detailed report is given in Reference 43. Briefly, four accident situations were considered:

(1) Spillage of liquid fuel blend into $N_2O_4$-air atmospheres.

(2) Spillage of liquid fuel blend onto a hot surface and subsequent contact of the vaporized fuel blend with $N_2O_4$-air atmospheres.

(3) Contact of vapors leaking from a container of fuel blend with $N_2O_4$-air mixtures.

(4) Passage of $N_2O_4$-air-fuel blend mixtures over an external ignition source.

Spillage of liquid fuel blend into $N_2O_4$-air mixtures was investigated over a range of temperatures by determining SIT at approximately one atmosphere in an apparatus described and discussed in Reference 3. The SIT is plotted versus $N_2O_4$ concentrations in air for liquid fuel blend, $N_2H_4$, and UDMH (Figure 8.1). The short horizontal lines on the curves in this figure represent the uncertainty of the $N_2O_4$ concentration measurement. In addition, the dew-point line for $N_2O_4$ is plotted (Reference 4).

The results given in Figure 8.1 show that the SIT of the fuel blend, $N_2H_4$, and UDMH differ little for $N_2O_4$ concentrations below 6%. Above 6% concentration, the SIT of the fuel blend is less than that of $N_2H_4$; above an $N_2O_4$ concentration of 9%, the SIT of the fuel blend is greater than that of UDMH. The double-valued nature of the SIT curves at the lower temperatures is due to the shift in $N_2O_4$ equilibrium with decreasing temperatures.
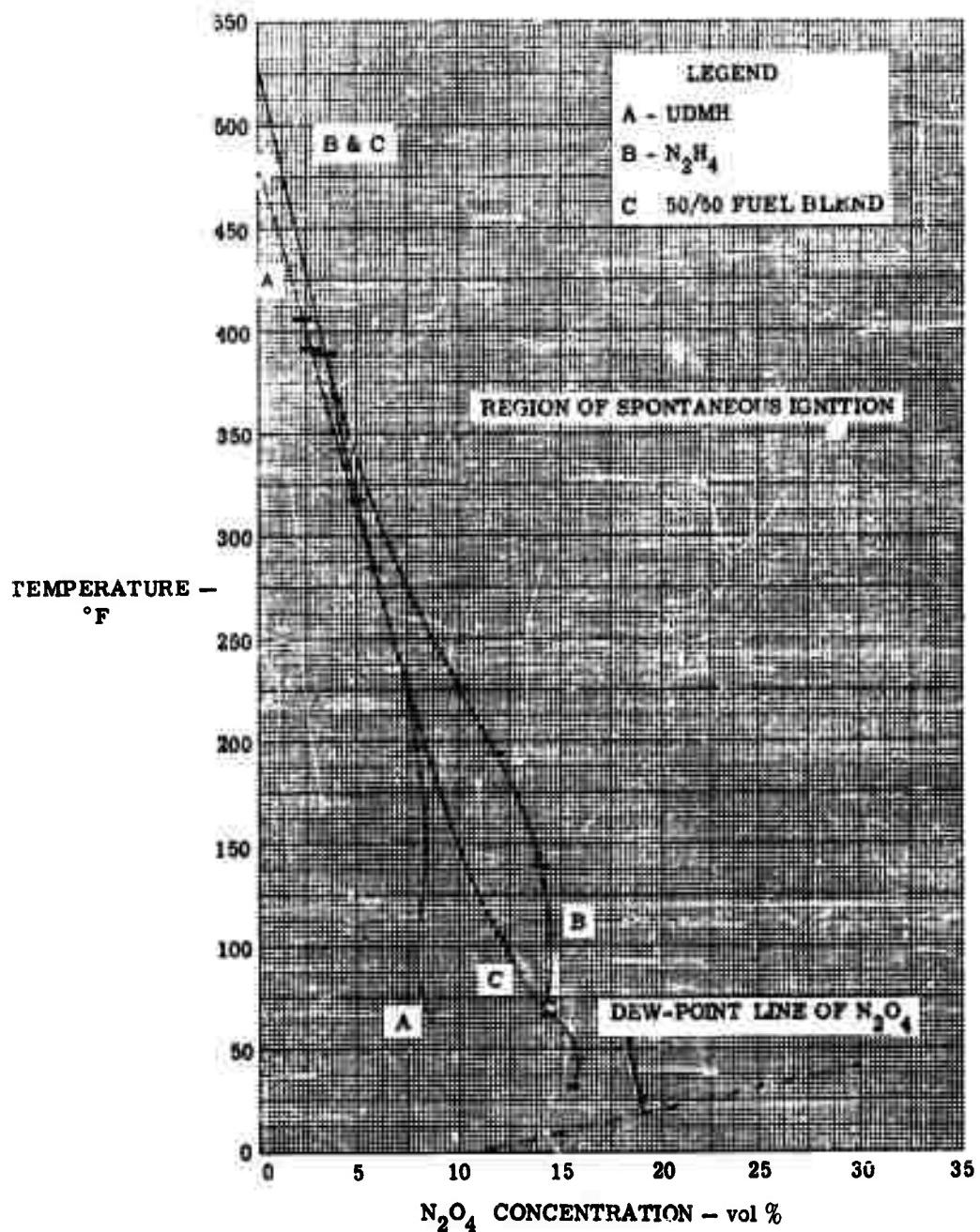
Figure 8.1. Spontaneous Ignition Temperatures of Liquid 50/50 Fuel Blend, $N_2H_4$, and UDMH
in Contact with $N_2O_4$-Air Mixtures at 740 ±10 mm of Hg as a
Function of $N_2O_4$ Concentration

Spillage of vaporized fuel blend into N$_2$O$_4$-air mixtures was investigated using the same apparatus. The tests were conducted by injecting N$_2$O$_4$-air mixture into an atmosphere of vaporized fuel blend-air mixture held at a specified temperature. Since vaporized fuel blend reacts with air, the residence time was held to one minute before injection of the N$_2$O$_4$-air mixture. The results shown in Figure 8.2 correspond to trials in which this residence time was used. The vertical arrows in the figure correspond to combustible concentrations below which ignitions were not obtained at temperatures up to 550°F.

Figure 8.3 shows a comparison between the SIT of vaporized fuel blend and UDMH in contact with 100% N$_2$O$_4$ vapors. The vertical dotted lines in Figure 8.3 represent the lower limits of flammability for each of the two combustibles in air at the maximum temperatures at which spontaneous ignition of each combustible air mixture was obtained in N$_2$O$_4$. The UDMH curve, unlike the fuel blend curve, extends to a combustible concentration equal to its lower limit of flammability in air at 360°F; the lower limit of flammability of the fuel blend is below the lower concentration limits at which spontaneous ignition occurs. This behavior may be due to the air oxidation of the N$_2$H$_4$ vapors in the vaporized fuel blend before the addition of N$_2$O$_4$.

Spontaneous ignition temperatures were determined for the equilibrium vapors of liquid fuel blend in contact with N$_2$O$_4$-air mixtures. Liquid fuel blend was evaporated at constant pressure from a vented container for a period of time sufficient to ensure vapor-liquid equilibrium. A mixture of N$_2$O$_4$ and air at room temperature (about 77°F) was injected into this vapor-air atmosphere and any ensuing reaction was noted. Sufficient liquid fuel blend was used to ensure that no appreciable change in its composition would occur. Results plotted in Figure 8.4 show the relation between the temperature of the equilibrium ignition and the composition of the N$_2$O$_4$-air mixtures which are injected into the hot vapors.

The vapors of N$_2$H$_4$ and UDMH from the fuel blend react in contact with N$_2$O$_4$ to produce a dense white cloud of fine particles, gaseous and solid. Such reactions were observed over a wide range of fuel concentrations at pressures as low as 2 mm of Hg. Because of this, flame propagation (flammability) tests conducted on N$_2$H$_4$ and UDMH in N$_2$O$_4$-air mixtures are, in reality, tests on the reaction products. The only combustibles found in the gaseous products were ammonia and hydrocarbons.
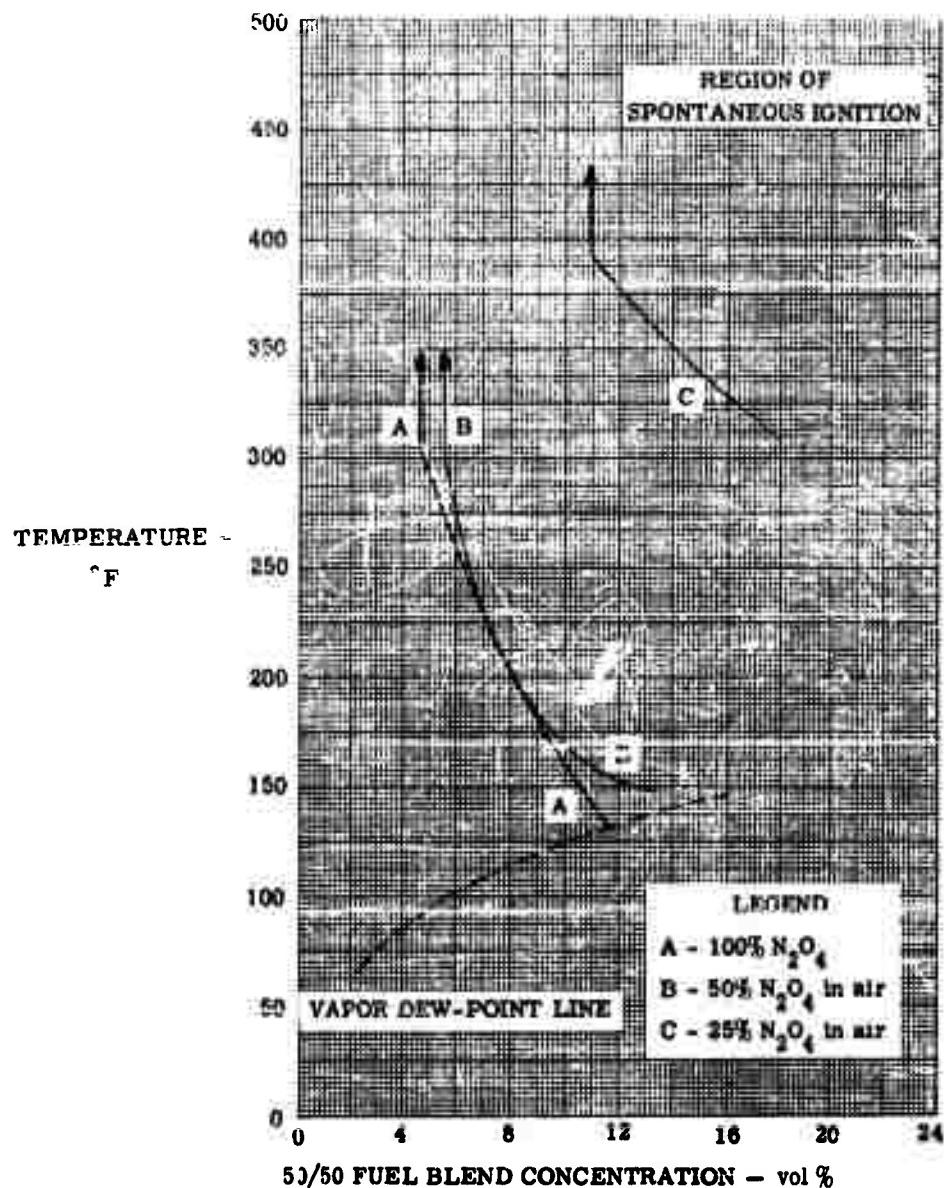
Figure 8.2. Spontaneous Ignition Temperatures of Vaporized Fuel Blend and Air Atmospheres in Contact with Various $N_2O_4$-Air Atmospheres at $740 \pm 10$ mm of Hg for Residence Times of One Minute
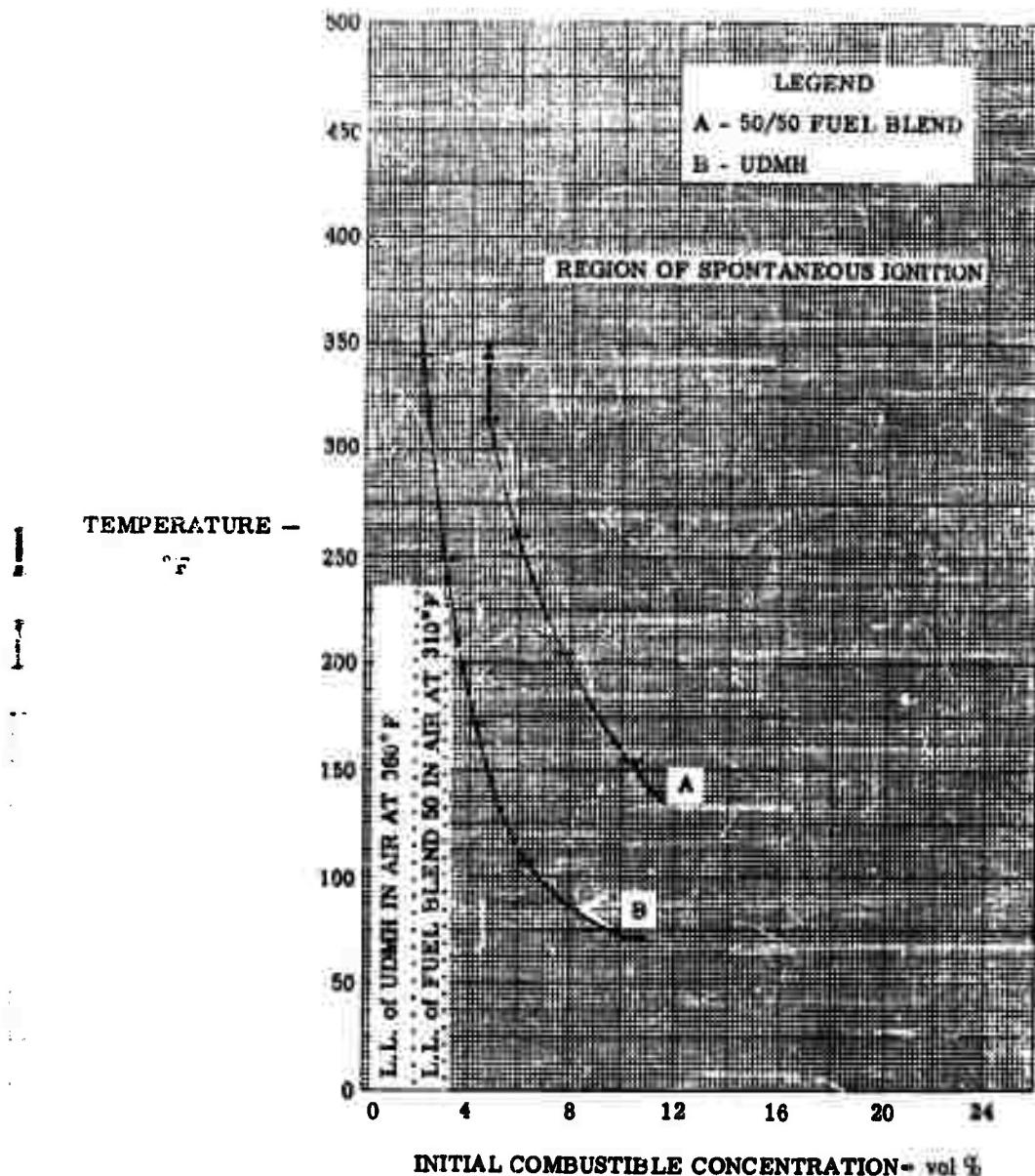
Figure 8.3. Spontaneous Ignition Temperatures of Vaporized (A) Fuel Blend-Air and (B) UDMH-Air Mixtures in Contact with 100% $N_2O_4$ at 740 ±10 mm of Hg as a Function of the Combustible Concentration in Air
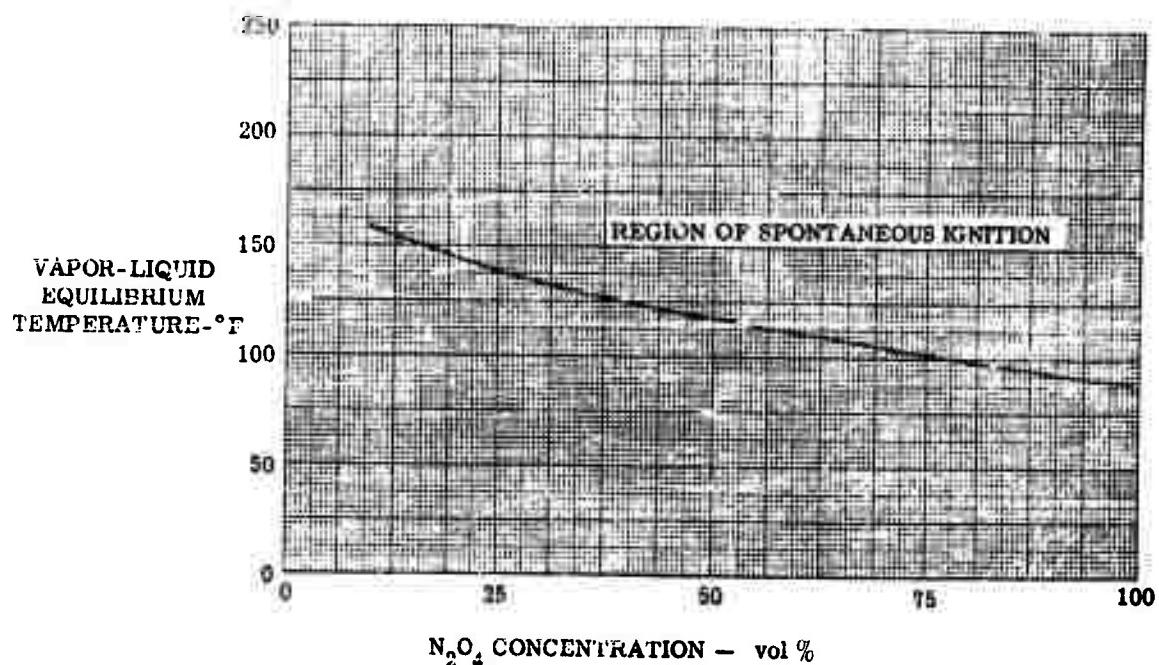
Figure 8.4. Vapor-Liquid Equilibrium Temperatures of Fuel Blend Required for Spontaneous Ignition of the Resulting Vapors in Contact with N₂O₄-Air Mixtures

In the absence of $N_2O_4$, the vapors of $N_2H_4$ and UDMH form flammable mixtures between 2.3 and 5.0 volume percent of the combustible vapor in air. The lower limits of flammability of $N_2H_4$-UDMH mixtures were calculated by using LeChatcliers' Law (Reference 38). Results of these calculations are given in Figure 8.5 where the lower limit concentration of combustible vapor ($N_2H_4$ plus UDMH) is plotted as a function of the concentration of UDMH in the combustible. Because of the high dew point of $N_2H_4$, not all of the vapor-air mixtures represented by points on the curve in Figure 8.5 are physically possible at 77°F and one atmosphere of pressure. Note that the portion of the curve corresponding to impossible vapor-air mixtures is dotted. The vertical line in the figure represents a combustible vapor composition equal to that of the fuel blend. To determine the lower limit of flammability of a realistic vapor-air mixture from Figure 8.5, the vapor composition must be known. Accordingly, the pressure-composition diagram for mixtures of $N_2H_4$ and UDMH at 72°F was determined and plotted in Figure 8.6. The dotted line in this figure corresponds to the vapor pressure of the fuel blend at 72°F. The intersection of this dotted line with the vapor curve gives the composition of the equilibrium vapors over liquid fuel blend at 72°F (80 mole percent UDMH and 20 mole percent $N_2H_4$). From Figure 8.5, the lower limit of flammability for this vapor mixture in air at 77°F is 2.6 volume percent. However, the presence of $N_2O_4$ in the air tends to increase the measured value because the $N_2H_4$ and UDMH is converted to gaseous and solid products not all of which are combustibles.
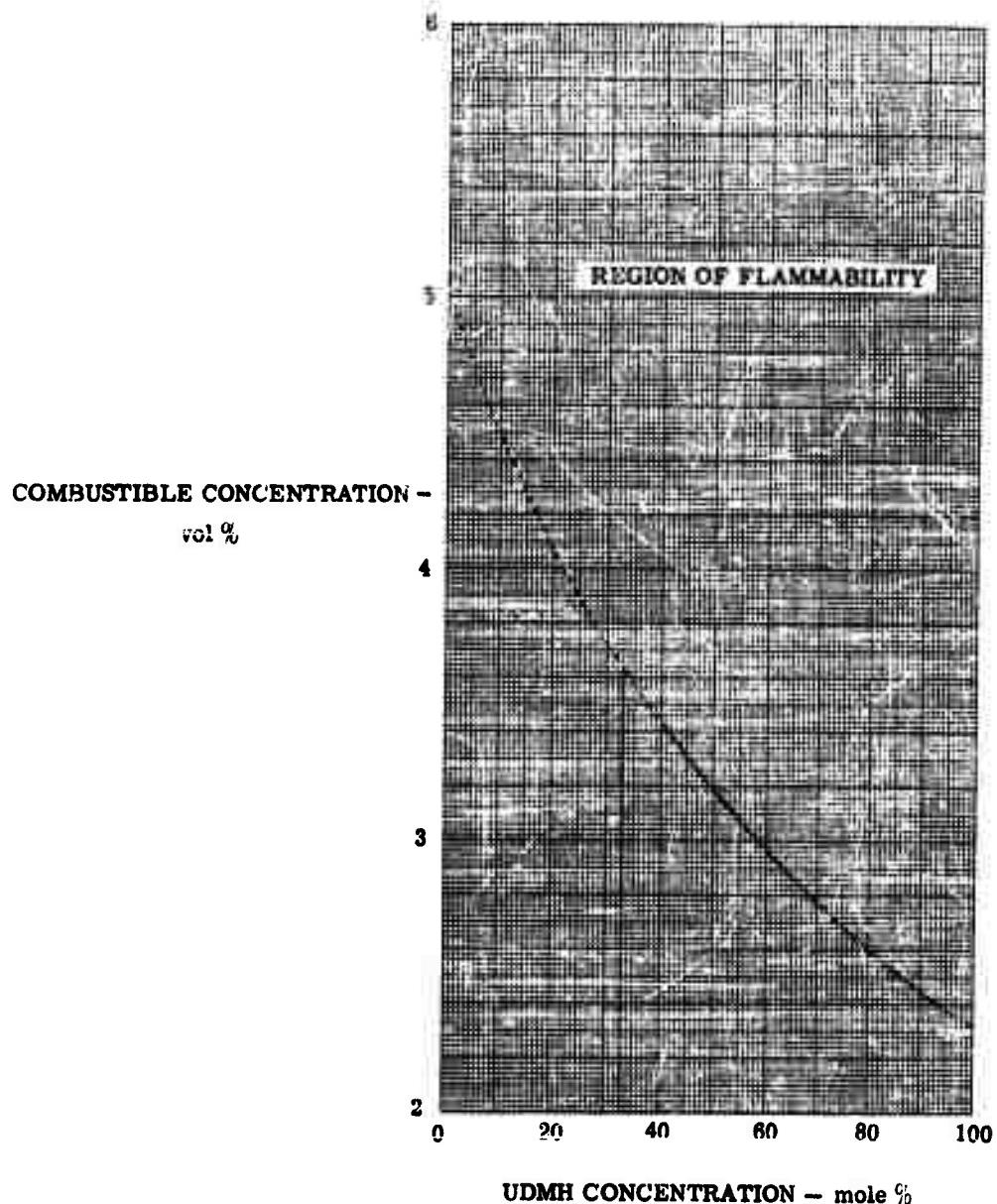
Figure 8.5. Lower Limit of Flammability of $N_2H_4$-UDMH Blend (Combustible) in Air at 77°F as a Function of UDMH Concentrations in Combustible
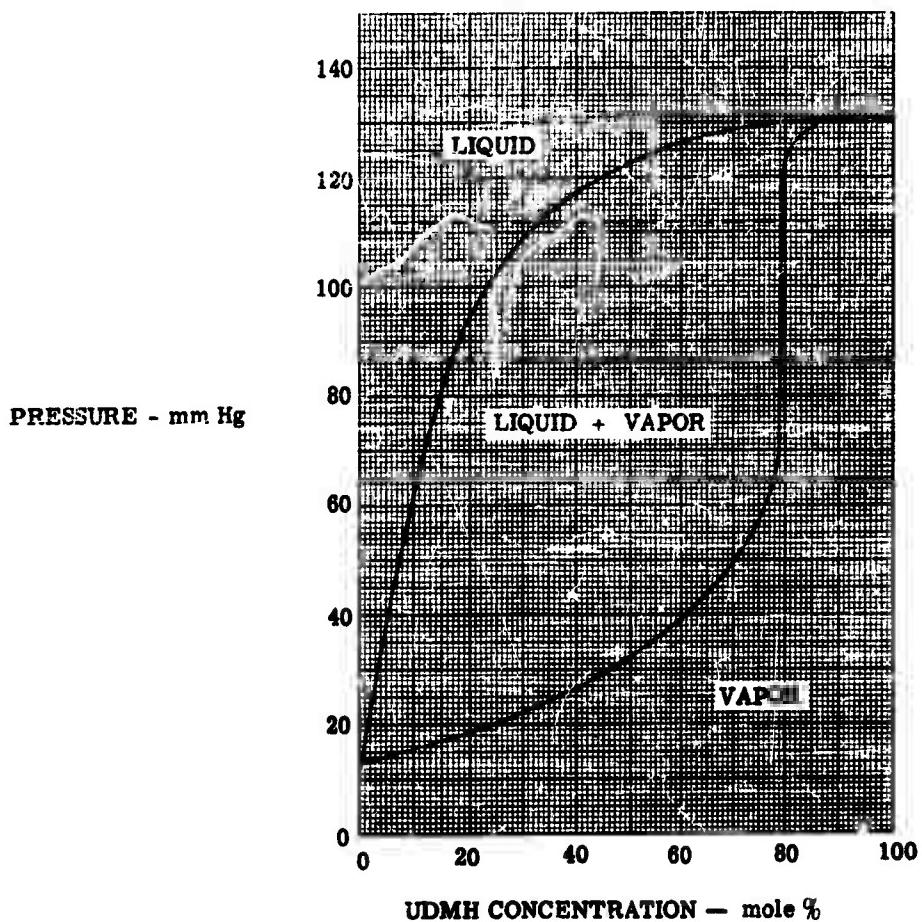
Figure 8.6. Pressure-Composition Diagram for the System $N_2H_4$-UDMH at 72°F

## 8.2   EXPLOSIVITY

Testing was conducted with laboratory quantities of $N_2O_4$ and the fuel blend
4) to determine whether or not propellant spills would lead to detonations.  In Refe
Penner distinguishes between explosions and detonations as follows.  In an explosi
lease rate and/or the number of molecules per unit volume increase with time mo
formly throughout a confined volume.  A detonation wave, on the other hand, is sp
and is propagated through unreacted combustible mixtures by an advancing shock f
exothermic chemical changes occur in such a way that the chemical heat released
support further propagation of the detonation wave.

A closed chamber, approximately 1/150-scale version of the actual Titan II
propellant spill tests (References 2 and 4).  Spills were conducted with laboratory
and fuel blend at various mixture ratios with fuel leads and oxidizer leads.  The la
combined propellants spilled into the chamber at a 2:1 mixture ratio was 0.1 pound
this mixture ratio, when 0.066 pound (30 grams) of $N_2O_4$ was added to 0.033 pound
fuel blend, an explosion occurred damaging the test chamber.

Based upon these tests, the following facts are presented:

(1)  Spillage of these propellants may cause explosions, but not detonations.

(2)  An increase in propellant quantity increases the reaction violence.

(3)  For the most part, spills are more reactive when fuel is added to the ox
the oxidizer is added to the fuel at identical quantities and mixture ratio

Multiple spill tests were performed by Rocketdyne (Reference 40) on the Tita
Spills were conducted with 50 and 300 pounds of propellants in simulated Titan II o
scale and 1/18-scale versions).  A 2-to-1 oxidizer-to-fuel ratio by weight was use
The following spill conditions were employed:  simultaneous spills into a dry silo,
spills, fuel lead spill, and one simultaneous spill into water.  Small-scale spills on
concrete also were conducted with 2.5 pounds of propellants.  The data reported by
indicates that all explosions result from vapor phase reactions.  In addition, the fol
tion was reported:

(1)  Silo spills with fuel leads were less severe than with either the simultan
leads.  The simultaneous spills resulted in the most violent explosions.

(2)  Increase in propellant weight increased the reaction violence on spills m
simultaneous and oxidizer lead conditions; however, fuel leads resulted i
in reaction violence.  The maximum overpressures measured for the 300
tests were equivalent to 2 pounds of TNT; for the 50-pound spill tests, 0.

8.2 EXPLOSIVITY

Testing was conducted with laboratory quantities of N$_2$O$_4$ and the fuel blend (References 2 and 4) to determine whether or not propellant spills would lead to detonations. In Reference 39, S.S. Penner distinguishes between explosions and detonations as follows. In an explosion, the heat release rate and/or the number of molecules per unit volume increase with time more or less uniformly throughout a confined volume. A detonation wave, on the other hand, is spacially non-uniform and is propagated through unreacted combustible mixtures by an advancing shock front behind which exothermic chemical changes occur in such a way that the chemical heat released can be utilized to support further propagation of the detonation wave.

A closed chamber, approximately 1/150-scale version of the actual Titan II silo, was used for propellant spill tests (References 2 and 4). Spills were conducted with laboratory quantities of N$_2$O$_4$ and fuel blend at various mixture ratios with fuel leads and oxidizer leads. The largest quantity of combined propellants spilled into the chamber at a 2:1 mixture ratio was 0.1 pound (45 grams). At this mixture ratio, when 0.066 pound (30 grams) of N$_2$O$_4$ was added to 0.033 pound (15 grams) of fuel blend, an explosion occurred damaging the test chamber.

Based upon these tests, the following facts are presented:

(1) Spillage of these propellants may cause explosions, but not detonations.

(2) An increase in propellant quantity increases the reaction violence.

(3) For the most part, spills are more reactive when fuel is added to the oxidizer than when the oxidizer is added to the fuel at identical quantities and mixture ratios.

Multiple spill tests were performed by Rocketdyne (Reference 40) on the Titan II propellants. Spills were conducted with 50 and 300 pounds of propellants in simulated Titan II open silos (1/10-scale and 1/18-scale versions). A 2-to-1 oxidizer-to-fuel ratio by weight was used on all tests. The following spill conditions were employed: simultaneous spills into a dry silo, oxidizer lead spills, fuel lead spill, and one simultaneous spill into water. Small-scale spills on dirt, water, and concrete also were conducted with 2.5 pounds of propellants. The data reported by Rocketdyne indicates that all explosions result from vapor phase reactions. In addition, the following information was reported:

(1) Silo spills with fuel leads were less severe than with either the simultaneous or oxidizer leads. The simultaneous spills resulted in the most violent explosions.

(2) Increase in propellant weight increased the reaction violence on spills made under simultaneous and oxidizer lead conditions; however, fuel leads resulted in a decrease in reaction violence. The maximum overpressures measured for the 300-pound spill tests were equivalent to 2 pounds of TNT; for the 50-pound spill tests, 0.2-pound of TNT.

(3) The addition of water to the bottom of the silo reduced maximum temperatures and pressures resulting from the reaction of the propellants.

The Atlantic Research Corporation (Reference 25) reported two explosions when laboratory quantities of propellants were mixed. When 0.006 pound (2.7 grams) of 50/50 fuel blend was spilled onto 0.033 pound (15 grams) of $N_2O_4$, one explosion occurred during five tests; however, when 0.10 pound (4.5 grams) of $N_2O_4$ was spilled onto 0.006 pound of fuel blend, an explosion occurred for the one test. No pressure measurements were reported for any of these tests since the primary purpose of this work was to study control of fires involving $N_2H_4$-type fuels with air and $N_2O_4$.

## 8.3   REACTION PRODUCTS

During the spontaneous ignition temperature and flammability tests conducted by the U. S. Bureau of Mines, a dense white cloud of fine particles was formed when the vapors of the propellants react. The gaseous products obtained when $N_2H_4$ and UDMH vapors and an excess of $N_2O_4$ vapors combined were analyzed with a mass spectroscope. These gaseous products are shown in Table 8.1. An infrared absorption spectrum of the solids from both reactions also was obtained and the predominant structural groups and their corresponding wavelengths are given in Table 8.2.

No specific information is available concerning the products of combustion of the 50/50 fuel blend and the oxidizer. Only theoretical products can be predicted, such as carbon monoxide, carbon dioxide, water, nitrogen, and certain chemical radicals.

### TABLE 8.1

### MASS SPECTROSCOPE ANALYSES OF THE GASEOUS PRODUCTS OF REACTION BETWEEN EXCESS $N_2O_4$ AND $N_2H_4$ AND EXCESS $N_2O_4$ AND UDMH AT 20 mm OF Hg AND 77°F

|  | Reactants | |
| --- | --- | --- |
| Products | $N_2H_4$ (mole %) | UDMH (mole %) |
| $N_2O$ | 30 | 35 |
| $N_2$ | 38 | 34 |
| $H_2O$ | 29 | 27 |
| $NH_3$ | 2 | 0 |
| Hydrocarbons | -- | 4 |

TABLE 8.2

STRUCTURAL GROUPS ASSOCIATED WITH ABSORPTION PEAKS
IN THE INFRARED ABSORPTION SPECTRA OF THE
SOLID PRODUCTS OF REACTION BETWEEN $N_2H_4$ AND $N_2O_4$
AND BETWEEN UDMH AND $N_2O_4$ AT 22 mm OF Hg AND 77°F

| $N_2H_4$ | | UDMH | |
|---|---|---|---|
| Wavelength (microns) | Structural Groups | Wavelength (microns) | Structural Groups |
| 3.0 | N-H (not H bonded) | 2.8 | OH |
| 3.1 | OH (H bonded) | 3.2 | NH, OH |
| 6.3 | N-H (bonding) | 3.4 | C-H |
| 6.5 | | 5.8 | $> C = O$ |
| | | 6.2 | - COOH |
| | | 6.8 | $CH_2$ or $CH_3$ |
| | | 7.2 | $R_2N-N = O$ |
| | | 7.9 | $R_2N-N = O$ |
| | | 9.6 | $R_2N-N = O$ |

**SECTION 9.0**

**REFERENCES**

SECTION 9.0

REFERENCES

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# APPENDIX

## VENDOR INDEX FOR NONMETALLIC MATERIALS

# APPENDIX

## VENDOR INDEX FOR NONMETALLIC MATERIALS

**CERAMICS**

| | |
|---|---|
| Sauereisen 47, 31, and P-1 | Sauereisen Cements Co., Pittsburgh, Pennsylvania |
| Temporell 1500 | Not Known |

**GRAPHITES**

| | |
|---|---|
| Graphitar 2 | U. S. Graphite Co., Saginaw, Michigan |
| Graphitar 50 | U. S. Graphite Co., Saginaw, Michigan |
| Johns Mansville No. 60 | Johns Mansville Co., New York, New York |

**PLASTICS**

| | |
|---|---|
| Armalon 7700, 7700B | DuPont, Wilmington, Delaware |
| Delrin | DuPont, Wilmington, Delaware |
| Fluorobestos | Fluorocarbon Company, Fullerton, California |
| Fluorogreen | R. S. Hughes, Denver, Colorado |
| Garlock 900 | Garlock Packing Co., Culver City, California |
| Genetron GCX3B | Allied Chemical and Dye Corp., New York, New York |
| Genetron XE2B | Allied Chemical and Dye Corp., New York, New York |
| Hypalon 20 | Dow Corning Corp., Midland, Michigan |
| Kel-F 300 | Minnesota Mining and Manufacturing Co., St. Paul, Minnesota |
| Kel-F (unplasticized) | Minnesota Mining and Manufacturing Co., St. Paul, Minnesota |
| Lexan | Dow Chemical Co., Midland, Michigan |
| Marlex 50 | Phillips Chemical Co., Bartlesville, Oklahoma |
| Marlex 5003 | Phillips Chemical Co., Bartlesville, Oklahoma |
| Moplen | Chemore Corp., New York, New York |
| Mylar | DuPont, Wilmington, Delaware |
| Nylon 31, 63, 101 | DuPont, Wilmington, Delaware |
| Plexiglass | Rohm and Haas Co., Philadelphia, Pennsylvania |
| Polyethylene HD | Visking Corp., Chicago, Illinois |
| Polyethylene (irradiated) | General Electric, Pittsfield, Massachusetts |

## PLASTICS (CONT)

| | |
|---|---|
| Polypropylene | Campco Division, Chicago Molded Products, Chicago, Illinois |
| Raythene N | Ray Chem Corp., Redwood City, California |
| Saran | Dow Chemical Co., Midland, Michigan |
| Teflon Asbestos | Fluorocarbon Co., Fullerton, California |
| Teflon FEP | DuPont, Wilmington, Delaware |
| Teflon Graphite | Fluorocarbon Co., Fullerton, California |
| Teflon Molydisulfide | Fluorocarbon Co., Fullerton, California |
| Teflon TFE | DuPont, Wilmington, Delaware |
| Teflon TFE Felt 7550 | DuPont, Wilmington, Delaware |
| Teslar 30 | DuPont, Wilmington, Delaware |
| Trithene A | Visking Corp., Chicago, Illinois |
| Ultron | Monsanto Chemical Co., St. Louis, Missouri |

## BUTYL RUBBERS

| | |
|---|---|
| Enjay 268 | Enjay Co., Inc., New York, New York |
| 551 | Enjay Co., Inc., New York, New York |
| Garlock 22 | Garlock Packing Co., Culver City, California |
| Goshen 1357 | Goshen Rubber Co., Inc., Goshen, Indiana |
| Hycar 2202 | B. F. Goodrich Chemical Co., Cleveland, Ohio |
| Linear 7806-70 | Linear, Inc., Philadelphia, Pennsylvania |
| Parco 805-70 | Plastics and Rubber Products Co., Los Angeles, California |
| Parco 823-70 | Plastics and Rubber Products Co., Los Angeles, California |
| Parker B496-7 | Parker Seal Co., Cleveland, Ohio |
| Parker B480-7 | Parker Seal Co., Los Angeles, California |
| Parker XB800-71 | Parker Seal Co., Cleveland, Ohio |
| Parker 318-70 | Hercules Packing Co., Lancaster, New York |
| Precision 9257 | Precision Rubber Products Corp., Dayton, Ohio |
| Precision 9357 | Precision Rubber Products Corp., Dayton, Ohio |
| Precision 214-907-9 | Precision Rubber Products Corp., Dayton, Ohio |
| Stillman 613-75 | Stillman Rubber Co., Culver City, California |

## FLUOROSILICONE AND FLUORORUBBERS

| | |
|---|---|
| Fluorel | Minnesota Mining and Manufacturing Co., St. Paul, Minnesota |
| Hadbar 58789-23GT | Hadbar, Inc., Temple, California |
| Hadbar 58789-23 | Hadbar Inc., Temple, California |
| Kel-F 3700, 5500 | Minnesota Mining and Manufacturing Co., St. Paul, Minnesota |
| Parker 1235 Series | Parker Seal Co., Los Angeles, California |
| Parker V-494-7 (Viton B) | Parker Seal Co., Cleveland, Ohio |
| Silastic LS 53 | Dow Corning Corp., Midland, Michigan |
| Silastic LS 63 | Dow Corning Corp., Midland, Michigan |
| Stillman Rubber EX774-M-1 (Viton B) | Balanrol Corp., Niagara Falls, New York |
| Stillman SI 277-70 (Viton A) | Balanrol Corp., Niagara Falls, New York |
| Stillman TH 1057 | Stillman Rubber Co., Culver City, California |
| TFNM-TFE | U. S. Army Quartermaster Research and Engineering Center, Natick, Massachusetts |

## POLYBUTADIENE RUBBERS

| | |
|---|---|
| Acushnet SWK 849 SWK 850 SWK 851 BWK 422 | Acushnet Process Co., New Bedford, Massachusetts |
| Stillman EX904-90 (Hydropol) | Stillman Rubber Co., Culver City, California |

## MISCELLANEOUS RUBBERS

| | |
|---|---|
| Buna N | B. F. Goodrich Chemical Co., Cleveland, Ohio |
| Cohrlastic 500 | Connecticut Hard Rubber Co., New Haven, Connecticut |
| Neoprene | Delta Products, Houston, Texas |

## PAINTS

| | |
|---|---|
| Alkyd No. 4 | Not Known |
| Catalac | Finch Paint and Chemical Co., Torrance, California |
| Chex-Wear | Benjamin Moore and Co., New York, New York |
| Co-Polymer P-200G | Co-Polymer Chemicals, Inc., Livonia, Michigan |
| Corrosite Clear 581 | Corrosite Co., Chrysler Building, New York, New York |
| Epoxy 1, 5, 7, 9, and 6809 | Not Known |

PAINTS (CONT)

| | |
|---|---|
| Floor Enamel 41138 | Schade and Co., Buffalo, New York |
| Primer MIL-P-6889 | Not Known |
| Primer CA 9747 | Sherwin Williams Co., Cleveland, Ohio |
| Tygon K | U. S. Stoneware, Plastics and Synthetic Division, New York, New York |

COATINGS AND ADHESIVES

| | |
|---|---|
| Armstrong A-6 | American Cyanamid Co., Oakland, California |
| EC 847 | Minnesota Mining and Manufacturing Co., St. Paul, Minnesota |
| HT 424 | Not Known |
| Rockflux | Flexrock Co., Philadelphia, Pennsylvania |

LUBRICANTS, GREASES, AND OILS

| | |
|---|---|
| Andok C | Esso Standard Oil Co., New York, New York |
| DC 11 | Dow Corning Corp., Midland, Michigan |
| DC 55 | Dow Corning Corp., Midland, Michigan |
| DC High Vacuum Grease | Dow Corning Corp., Midland, Michigan |
| Drilube 703 | Drilube Co., Glendale, California |
| Electrofilm 66C | Not Known |
| Halocarbon Grease | Halocarbon Products Corp., Hackensack, New Jersey |
| Kel-F 90 | Minnesota Mining and Manufacturing Co., St. Paul, Minnesota |
| L 1114 Oil | Minnesota Mining and Manufacturing Co., St. Paul, Minnesota |
| LOX Safe | Redel Corp., Anaheim, California |
| Microseal 100-1, 100-1 CG | Microseal Products Sales, Torrance, California |
| Molykote Z | Alpha Molykote Corp., Stanford, Connecticut |
| Nordcoseal 147, 421 | Rockwell Manufacturing Co., Pittsburgh, Pennsylvania |
| Polyglycol Oils | Dow Chemical Co., Midland, Michigan |
| QC-2-0093 | Not Known |
| QC-2-0026 | Not Known |
| Rayco 30 and 32 | Not Known |
| Rockwell-Nordstrom No. 950 | Rockwell Manufacturing Co., Pittsburgh, Pennsylvania |

## LUBRICANTS, GREASES, AND OILS (CONT)

S#58-M Oil — New York and New J. Lubricating Co., New York

TMSF 1, 2, 3 — Not Known

UDMII Lube 50/50 Mixture of UDM Lube — Superlube, Inc., Clev. Ohio

and

Electro Mechanics No. 20057 — Electro Mech. Inc., New British Con.

Vydax A — DuPont, Wilmington, Delaware

## THREAD SEALANTS AND POTTING COMPOUNDS

Crystal M and CF — Not Known

Epon 828 — Shell Chemical Co., San Francisco, California

Fairprene 5159 — Not Known

$N_2O_4$ Sealant — Redel Corp., Anaheim, California

Paraplex P-43 — Not Known

Proseal 793 — Coast Proseal and Manufacturing Co., Los Angeles, California

PR 1422 — Products Research Co., Burbank, California

Reddy Lube 100, 200 — Redel Corp., Anaheim, California

RTV 20 — General Electric Co., Pittsfield, Massachu